Enhancing Agriculture in Africa: A U.S. Role in Development Assistance

Volume II--Contract Papers

Part D: Technology Papers

1. Soil Fertility Maintenance in Sub-Saharan Africa
   (Paul L.G. Vlek, A.U. Mokwunye, and M.S. Mudahar)
2. Crop Rotation and Residue Management
   (R. Lal)
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4. Soil and Water Management in the Humid and Highland Zones of Africa
   (Laurence A. Lewis)
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LOW-RESOURCE AGRICULTURE IN AFRICA

SOIL FERTILITY MAINTENANCE IN SUB-SAHARAN AFRICA

by

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SOIL FERTILITY MAINTENANCE IN SUB-SAHARAN AFRICA

INTRODUCTION

1.1. The agricultural sector dominates the economy of most of the countries of Africa. Food production increased approximately 1.9%/year between 1961 and 1980. Countering this progress is the nearly 3%/year increase in population over the same period, resulting in a per capita production decline of 1.1%. Indeed, the year 1983 marked the 16th time in the past 22 years that per capita food production has declined in this region.

1.2. Food production languishes in part because many of the governments in Africa are reluctant to allocate or are incapable of allocating sufficient funds to the basic building blocks of agricultural development: agricultural research, agricultural extension, rural infrastructure, and economic incentives. A broad-based agricultural development is crucial for increasing incomes, employment, and export earnings. Raising the incomes of the rural poor is essential for increasing government revenues and creating a domestic market for the goods and services produced in a rapidly growing urban sector. Availability of appropriate technical packages adapted to local conditions, timely supply of inputs, effective extension services, and reasonable pricing policies are all necessary elements for the revival of the ailing agricultural sector.

1.3. According to FAO, only 16% of the soil resources in Africa have no serious limitation for crop production. The remaining 84% of the soils are severely limited. It is extremely expensive to develop these soils and make them suitable for crop cultivation. Furthermore, productive soils are being lost through mismanagement, erosion, desertification, and deforestation. Approximately 2% of the arable land (4 million ha) is under irrigation. The development of irrigation systems is expensive and slow, and the prospects for irrigation development in sub-Saharan Africa are limited.

1.4. During 1980-82, the average cereal yield was less than 1 ton/ha in 26 of 39 countries in sub-Saharan Africa. Furthermore, in 22 of 39 sub-Saharan countries the average cereal yield declined from 1966-68 to 1980-82, a trend that has yet to be reversed. A large number of countries with negative growth in cereal yields already had low cereal yield levels. Lack of appropriate and economical agricultural technology appears to be a major constraint for increasing crop yields and accelerating agricultural growth.

1.5. Soil fertility in sub-Saharan Africa has been widely recognized as a major constraint (Eicher, 1986). Parent materials in tropical Africa are not uniformly distributed and the climate is diverse, resulting in considerable variability in inherent soil fertility. However, because of extensive weathering and/or intensive leaching, soils of tropical Africa have relatively low inherent fertility (Davies, 1973). Much of the nutrient reserves in these soils is associated with the organic matter, accumulated over the years at a rate dependent to a large degree on the rainfall conditions, as shown in Table 1.1 (Nye and Greenland, 1960). Traditional farming systems relied heavily on resting periods for the land to restore. The nutrient balance in such systems would depend on the duration of the cultivation and rest cycles. For Uganda an example was provided by Jones (1972):

Table 1.1. Nutrients Stored in the Aerial Cover of Fallow Vegetation and in the Soils (After Nye and Greenland 1960)

Location	Annual Rainfall	Type of Fallow	Nutrients Stored in the Aerial Cover of Vegetation and Litter					Nutrient Stored in the Soils in the first 30 cm				
			N	P	K	Ca	Mg	N	P	K	Ca	Mg
	(mm)		- - - - - - - -(kg/ha) - - - - -					- - - - - - - (kg/ha) - - - - - - -				
Kade (Ghana)	1,625	40-year old mature secondary forest	1,863	128	833	257	352	4,674	13	661	2,622	376
Yangambi (Zaire)	1,825	18-year old secondary forest	569	74	412	571		2,280	19	365	102	54
Yangambi (Zaire)	1,825	5-year old secondary forest	398	24	350	298						
Ejura (Ghana)	1,475	20-year old high grass savanna	27	8	47	35	26	1,824	23	194	2,964	388
Ejura (Ghana)	1,475	*Imperata cylindrica*	17	6	35	7	14					

Change in nutrient content and pH of the 0-45 cm depth of soil

	Measured After Resting Phase 1963-66	Measured After Arable Phase 1966-69
Organic carbon	+15,950	-19,700
Total nitrogen	+769	-968
Total phosphorus	+85	-88
Total sulfur	+45	-86
pH ($CaCl_2$)	+0.26	-0.31
Exchangeable K	+471	-461
Exchangeable Ca	+971	-1,897
Exchangeable Mg	+420	-420

Soil fertility declines rapidly during continuous cropping, reflected in reduced yields (Figure 1.1), even if a grain legume is part of the rotation (Figure 1.2).

1.6. Fertilizers play a vital role in stimulating food production in the developing world. Historical evidence shows that 36% of the yield increases achieved in developing market economies of Africa between 1948/52 to 1972/73 is due to rational use of fertilizers (Pinstrup-Andersen, 1976). The current fertilizer consumption rate in sub-Saharan Africa (approximately 6.4 kg nutrients/ha/year) is the lowest in the world. By comparison, in 1983 the average consumption rate was 85 kg/ha for the world, 33 kg/ha for Latin America, and 81 kg/ha for Asia (IFDC, 1986).[1] The statistic is more disturbing when it is recognized that much of this fertilizer is used on export crops rather than on food crops.

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[1] Consumption rates are on the basis of arable land and land under permanent crops.

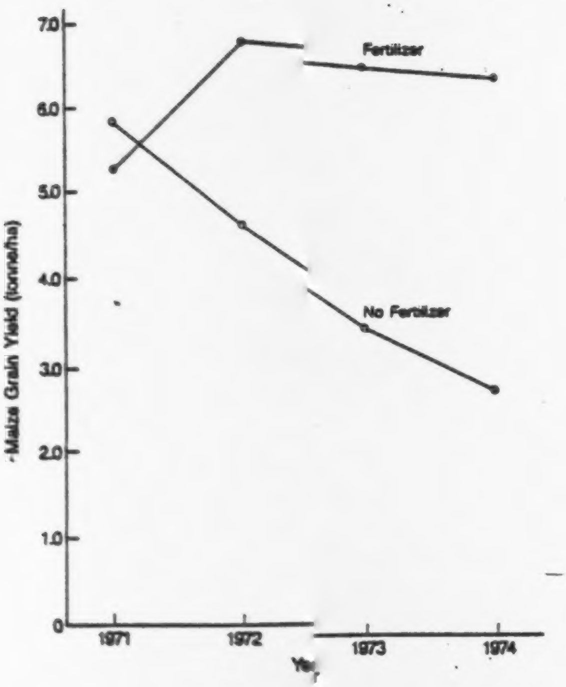

Figure 1.1. Long-Term Effect of Fertilizer (120 N, 66P, 30K, kg/ha Per Crop) on Maize Grain Yield Grown on an Alfisol in the Forest Zone of Nigeria (Source: Kang et al. 1977).

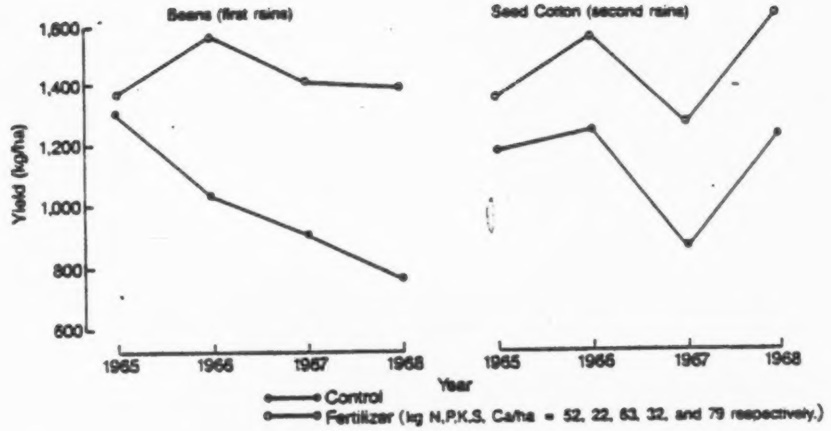

Figure 1.2. Effect of Annual Fertilizer Additions on Continuous Rotations of Bean and Cotton Grown on a Red Ferralitic Soil in Uganda (Source: Jones, 1972).

Estimated Share of Fertilizer Consumption by Crops in Selected Countries of Sub-Saharan Africa[a]

		Percent Share of NPK Consumption for									
Country	Year	Millet	Sorghum	Maize	Rice	Cotton	Ground-nuts	Sugar-cane	Coffee/Tea/Cocoa	Others	Total
Burkina Faso	1975	-	28	-	7	40	7	18	-	-	100
Cameroon	1977	-	-	-	4	-	-	41	3	52	100
Chad	1978	-	-	-	2	97	-	-	-	1	100
Gambia	1976	6	4	20	4	-	66	-	-	-	100
Ivory Coast	1973	-	-	2	3	24	-	23	1	47[b]	100
Malawi	1976	-	-	11	7	2	-	8	19	53[c]	100
Mali	1976	-	-	6	15	51	6	-	-	22	100
Niger	1983	49	5	-	19	2	13	-	-	12	100
Nigeria	1979	16	24	12	11	7	2	6	3	19[d]	100
Senegal	1975	36	-	-	20	13	31	-	-	-	100
Sudan	1975	-	-	-	2	46	-	6	-	46[e]	100
Tanzania	1975	-	-	21	-	19	-	5	27	28[f]	100

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a. Mudahar, 1986.
b. 31% for banana/pineapple and 16% for rubber/oil palm/coconut.
c. 33% for tobacco.
d. 13% for yams, cassava, and potatoes.
e. 27% for wheat.
f. 24% for tobacco.

The high cost of imported fertilizers and unavailability of foreign exchange are among the reasons preventing expansion of fertilizer consumption in this part of Africa.

1.7. The subject paper will analyze in greater detail the soil fertility constraints to crop production and the alternatives available to the low-resource farmer in sub-Saharan Africa or their governments to deal with this constraint.

TECHNOLOGY DESCRIPTION

2.1. The principal low cost means of augmenting the native fertility of the soil are:

- Use of manures.
- Use of biological nitrogen fixation.

- Use of indigenous nutrient sources.
- Use of microbial organisms to enhance nutrient availability.

Most of these methods have been used traditionally, knowingly or not by farmers the world over.

Manures

2.2. Manures are defined as any ratio of crop material, litter, and/or animal residues or dung, subjected to various degrees of fermentation. In those regions of sub-Saharan Africa where animals are a component of the farming system, substantial fractions of the harvested nutrients may pass through the animal. The quality of the manure produced may vary widely, depending on the animal species and the quality of the forage, as well as on the admixtures, storage and fermentation practices. Hemmingway (1961) reported the mean nutrient content of 50 farmyard manures from Africa to be 1.73% in N, 0.24% in P, and 1.29% K, 0.52% Ca, and 0.20% Mg. Across Francophone West Africa the variation in NPK levels of farmyard manure were reported to range from 0.48% to 1.95% for N, 0.06% to 0.57% for P, and 0.39% to 2.62% for K (Mokwunye, 1980).

2.3. AT the onset it should be pointed out that manuring does not generate nutrients. In fact, Richards (1984) estimated a nutrient balance for a farm in Rwanda where 3.8 tons of dry forage containing 370 kg of minerals produced approximately 2 tons of dry manure containing only 300 kg of mineral nutrients. Thus, the passage through the cattle results in net losses in organic matter as well as minerals (Neel, 1986).

2.4. The practice of manuring is a means of transferring soil fertility from pastureland to cropland, or returning some of the harvested nutrients to the field. While straw could be left in place, the production of manure requires effective means of collecting, storing, and redistributing large quantities of bulk material. The most effective means of collecting animal droppings is undoubtedly by feeding the stabled animal, yielding about eight times the animal weight in manure per year (Gros, 1967). Alternatively, the animal can be herded in private or communal pastureland during the day and be stabled at night, producing only 3.5 times the animal weight per year and thus reducing the rate of fertility transfer. The practice of herding without stabling, common for the nomadic populations of the sahel and savannah regions, does not benefit any cropland and is generally a drain on the soil resources with potentially calamitous results in the case of overgrazing.

2.5. The notion that manure is a free resource requires careful scrutiny. The lateral redistribution of soil fertility implies availability of pastureland, often a scarce resource in itself. Besides, the management of large quantities of manure (recommendations vary from applying 5 to 20 tons of fresh manure/ha) is labor intensive and requires transport and implements. The economics of manuring are therefore largely determined by the primary reasons for keeping animals (security, traction, meat, or milk). The manure becomes a byproduct that needs to be managed prudently in order to conserve soil fertility.

2.6. The benefits of manuring are manifold and well documented (Charreau, 1975). They include:

- Improvement in soil macro-structure through incorporation of organic matter or, for heavier soils, even through mulching.
- Increased water-holding capacity of the soil, particularly the topsoil.
- Improved aggregate stability leading to improved infiltration and erosion control.
- Prevention of soil hardening.
- Improvement in soil cation exchange capacity, of particular importance for the sandy soils of West and Southern Africa.

- Provision of a source for slowly releasing inorganic nutrients.
- Prevention of phsophate fixation by iron and aluminum oxides.
- Development of a favorable environment for microbial activity in the soil.

Although the integrated effect of manure applications will differ with soil type and climate, and the quantity of nutrients returned or added to the soil, there are few situations in Africa where use of organic manures in appropriate quantities will have adverse effects.

Biological Nitrogen Fixation

2.7. Biological nitrogen fixation (BNF) is the process of reducing atmospheric nitrogen under ambient temperature and pressure conditions by microbial organisms. Three categories of processes are known to exist:

- Symbiotic nitrogen fixation in legume-Rhizobium symbiosis and Azolla-Anabeana symbiosis.
- Rhizospheric nitrogen fixation by diazotrophs associated with root systems.
- Asymbiotic nitrogen fixation by free-living diazotrophs (bacteria or blue-green algae).

These processes are universal and their benefits accrue without intervention by the farmer. However, management decisions by the farmer will affect the extent of these benefits. These decisions concern the selection of crops and cropping systems, as well as farming practices than can modify the edaphic factors that play on BNF. Since cropping systems are the subject of several other OTA papers, these will not be discussed in detail here.

2.8. The production of ammonia in the BNF process is catalyzed by nitrogenase, an enzyme containing Mo, Fe, and S, and derives its energy from the electron donor ATP. The necessary carbohydrate is either provided through symbiosis or derived from soil organic matter. If derived from a host plant, a fraction of the photosynthate (8-17 kg of carbohydrate/kg of fixed N) may be sacrificed by the host plant, often at the expense of yield (Havelka et al., 1982). The attraction of BNF is that its benefits come to the farmer without great investment and risk.

2.9. The quantities of nitrogen fixed vary widely, and are dependent on crop and environmental conditions. Ayanaba (1980) provides some fixation rates reported in the literature for tropical regions:

Grain legumes	40-450 kg/ha/year
Forage legumes and cover crops	93-862 kg/ha/year
Tree and shrub legumes	74-584 kg/ha/year

The validity of these rates is questionable due to the difficulty in measuring BNF and the wide range of ecological conditions under which they were measured. For tropical farming conditions realistic BNF rates are more commonly on the lower end of these rates. It should be noted that, in the case of grain legumes, the majority of the fixed N is harvested with the seed which on average contains twice the level of N than the plant as a whole (Henzell and Vallis, 1977). The contribution of nonsymbiotic and associative nitrogen fixation is estimated at 100 kg N/ha/year (Greenland, 1980). Nonsymbiotic nitrogen fixation by photosynthetic bacteria and blue-green algae may provide 30 kg N/ha/year (Knowles, 1977), while Azolla-Anabeana symbiosis may fix from 0.4-3.3 kg N/ha/day (Van Berkum, 1984).

2.10. The soils of Africa are well infected with diazotrophs and Rhizobia for indigenous legumes, eliminating the need for inoculation. In fact, for grain legumes alone, Phillips and De Jong (1984) estimate that about 1 million tons of nitrogen are fixed in Africa. If forage and tree legumes and free living or associative BNF were included, this figure would rapidly multiply.

Similarly, Azolla pinnata var. africana has been observed in most sub-Saharan African countries south of the 15th parallel north (Reynaud, 1982).

2.11. Efforts to maximize the benefits of BNF are made worldwide. More advanced research such as gene transfer is concentrated in the west and, if successful, may with time find its place in the African context. The current technology of BNF is principally related to the inoculation with effective strains of Rhizobium. Selection of these strains, their multiplication, inoculant manufacture, and application to the field are techniques that are well advanced and described (Havelka et al., 1982). Nonetheless, the use of inoculant is limited in sub-Saharan Africa. Apparently, in Zambia, Kenya, Zimbabwe, and Rwanda, legumes are routinely inoculated by commercial farmers. However, the inoculated legumes are introduced ones such as soybeans. Where indigenous legumes are grown, improvements in nitrogen fixation through seed inoculation would be difficult to demonstrate (Ayanaba, 1980). The difficulty in obtaining benefits from inoculation is reflected in the experimental results reported by Delvaux, 1982 (Table 2.1). The introduction of Azolla in rice cultures in Africa is only in an experimental stage.

Mycorrhizae

2.12. Mycorrhizae are species of fungi that attach themselves to plant roots resulting in a symbiotic relationship between these fungi and the host plant that can lead to increased yields. There are two major groups of mycorrhizae--ectomycorrhizae and endomycorrhizae. The latter, vascular-arbuscular or VA mycorrhizae (VAM), named for their ability to penetrate the cortical cells of vascular plants, are the most important group for agronomic crops. The VAM hyphae grow into the soil and take up nutrients which are then translocated to the roots of the host. The hyphae thus extend the root system,

Table 2.1. Yields of Peanuts

Experiment Location	Check	Nitrogen Fertilizer	Laboratory Inoculation	Nitrogen Inoculation
	(kg/ha)			
Sahelian Zone				
Ouahigouya	1,545	2,500	1,563	1,701
Ouahigouya	2,153	2,257	1,580	2,083
Ouahigouya	1,911	2,604	1,528	1,545
Ouahigouya	2,326	2,792	2,772	2,535
Bougounam	903	1,530	1,007	1,339
Moyenne	1,285	1,389	1,319	1,319
Sudanian Zone				
Oronkua	633	753	833	856
Oronkua	698	867	895	1,160
Tiankoura	883	880	738	671
Diebougou	914	957	1,068	1,080
Diebougou	756	1,065	586	784
Moyenne	711	843	792	882

After: Delvaux, 1982.

much in the way of root hairs, providing an increased surface area for absorption of nutrients. This is particularly useful for the more immobile nutrients such as phosphorus, zinc, and copper. The increase in phosphorus uptake by cassava inoculated with VA mycorrhizae in Nigeria is shown below:

		P Concentration	P Uptake
	Inoculated	In Cassava Tops	
Soil Treatment	Glomus Mosseae	% P	mg P
Sterilized	no	0.11	1.30
	yes	0.14	16.7
Unsterilized	no	0.08	6.08
	yes	0.09	6.22

Adapted from Kang, Islam, Sanders, and Ayanaba, 1980.

2.13 Most agricultural soils have indigenous endophytes. However, infection by these indigenous endophytes tends to be erractic, perhaps due to the uneven distribution of the propagules in the virgin soils. Many crops such as maize, cowpea, and onion cannot take up phosphorus from low-P soils unless their roots are infected with effective strains of mycorrhizal fungi. Inoculation requires multiplication of the efficient strains in special plots. The data above show that the effectiveness of an introduced strain depends on its ability to withstand competition from the indigenous strains. Thus, it has been easier to show the benefits of mycorrhizal association in sterilized than in unsterilized soil.

2.14. There have been reported instances of improvements in the utilization of sparingly soluble phosphorus sources such as phosphate rock (PR) when applied to crops infected with VAM. Howeler and Sieverding (1983) working with cassava in Colombia observed that responses of the inoculated crop were independent of the solubility of the phosphate source. In contrast, in an earlier study with cassava in Nigeria, Kang et al. (1980) noted that mycorrhized cassava utilized phosphorus more efficiently from the more reactive Morocco PR than from the Togo PR, leaving this issue unresolved.

2.15. Several trials, both within (Sanni, 1976; Islam et al., 1980) and outside Africa (Howeler et al., 1982) have shown that the combination of phosphate rock and mycorrhizae is most effective in soils of low P status. Mycorrhizal infection of roots seems to decline with an increase in P concentration in soil solution as indicated below:

Soil P Level mg P/Liter	Infection Level in Cowpea
0.003	Very frequent occurrence of hyphae
0.012	Frequent occurrence
0.100	Occasional occurrence
0.800	Detectable presence

Adapted from Yost, 1984.

To complicate matters, there are suggestions (Menge et al., 1978) that mycorrhizal infection is reduced not by high levels of P in the soil, but by high levels in the host plant. It has also been suggested that infection in soils with high P levels is enhanced if other growth factors are optimized. The most recent results from trials in Colombia (CIAT, 1986) indicate that adequate supplies of fertilizer seem to promote mycorrhizal efficiency, resulting in significantly improved tuber yield (Figure 2.1).

2.16. Other tentative observations include the following:

- Addition of mycorrhizae will give the biggest proportional increase in crop performance when the response curve to phosphate rock addition alone is still in the rising section.
- Mycorrhizal activity is favored by high temperatures such as are encountered in most of tropical Africa.
- A combination of limited moisture and low P tends to favor enhanced mycorrhizal activities (Kwapata and Hall, 1985). This phenomenon is often seen with crops that are adapted to semiarid conditions.

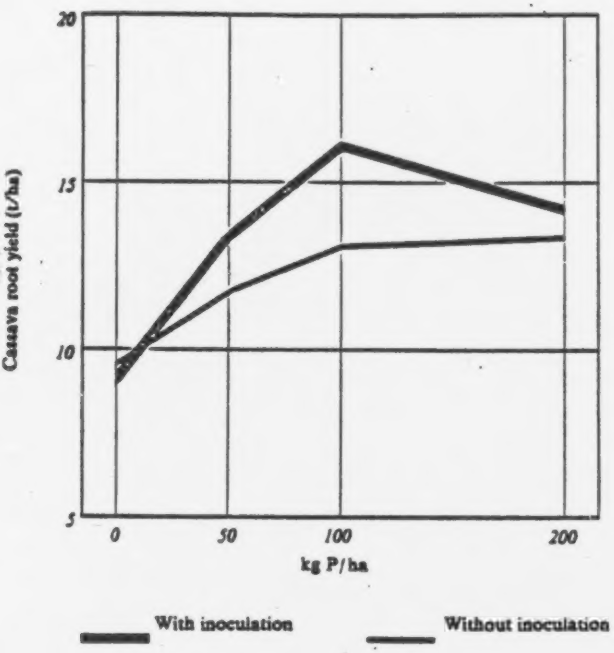


Figure 2.1. Effect of P and Inoculation on Cassava Yield.

Source: CIAT 1986.

2.17. There is little doubt that improvements in mycorrhizal technology will help farmers in the phosphorus poor soils of tropical Africa to make efficient use of P from all sources. Similar to BNF, success of mycorrhizal technology depends on inoculation of crops with effective strains of the fungi which can survive and compete with the indigenous endophytes. Unlike BNF, however, all attempts but one to culture VAM on artificial media have failed. It is therefore very difficult to obtain pathogen-free inoculum in quantity. There is a lot to be done before VAM technology will find its entry into African agriculture. Even if it is, it seems that VAM is not likely to reduce the need for organic and inorganic fertilizer but will play a role in concert with those inputs.

Indigenous Mineral Resources

2.18. Higher crop yields, multiple and continuous cropping as well as increased crop yields will not be possible in sub-Saharan Africa without an increase in fertilizer use. On a continental scale, Africa consumed 3.4 million mt of fertilizer nutrients in 1984/85, representing 2.7% of the world's consumption. Of this total, Egypt and South Africa consumed more than one-half. Five countries, only one of which (Nigeria) is in sub-Saharan Africa, consumed 73% of the fertilizers used by the continent in 1984/85 leaving the remaining 45 countries with a share of 27%. On the regional level, the 3-year average (1980/81 to 1982/83) for amount of fertilizer consumed by sub-Saharan Africa was 1 million mt. This constitutes 0.9% of the world fertilizer consumption for a region that contains roughly 6% of the world's population.

2.19. The aggregate consumption varies from country to country. Nigeria, Zambia, and Zimbabwe account for 50% of the total consumption in sub-Saharan Africa. In more than 50% of the countries of the region, fertilizer consumption is less than 5,000 mt of nutrients annually and the regional consumption rate is less than 7 kg of nutrients/ha for both cash and food crops. Only a small percentage of cropped area is actually fertilized; thus actual use rates are much higher than what is indicated by the average. With the exeption of a few countries such as Nigeria and Niger, about one-half to two-thirds of the fertilizer is used on cash crops. The high risk due to inadequate markets and uncertainty in weather conditions cause many farmers to be averse to use of fertilizer on food crops. Other factors responsible for low usage on food crops are:

- Lack of foreign exchange for fertilizer import.
- Lack of credit to farmers for fertilizer purchase.
- Shortcomings in fertilizer research which often result in poor use.

Increased population pressure has led to utilization of marginal lands for food crop production. The net effect is that although land under cultivation has increased, yield per hectare has actually fallen even in those countries where fertilizers have been applied to food crops. For example, yield of sorghum in Africa decreased from ≅700 to ≅600 kg/ha between around 1970 and 1984, while land under sorghum increased by 20% (FAO, 1978, 1985).

2.20. All of the mineral resources needed to manufacture chemical fertilizers occur to varying degrees in sub-Saharan Africa. Many of the mineral occurrences have not been exploited, and insufficient data exists on the quantity and quality of the various deposits. Present data suggest that there may be adequate quantities of phosphate and nitrogen raw materials but not enough of the potash and sulfur resources to meet the needs of the region. It is not known if the exploitation of these resources is technically and economically feasible under the present conditions. The advantages of utilizing indigenous resources to meet their needs, even in times of adequate world supply, may include supply security, foreign exchange savings, reduced transportation cost, and generation of employment.

2.21. The identification of P deficiency as a major soil constraint, and the existence of PR deposits in 26 sub-Saharan African countries (Figure 2.2) has resulted in an initial emphasis on raw material studies involving PR by both national and international research organizations (McClellan and Notholt, 1986). Phosphate rock (PR) occurs as sedimentary and igneous deposits, the majority being of sedimentary origin. The information on these deposits is highly variable. Only in a few cases is the geology, mineralogy, petrograhy, chemistry, reserves, and processing quality fully described. Mostly, the descriptions are fragmentary and concentrate on one or two features which rarely include the economic geology. The lack of professional and financial resources often has prevented the countries of the region from inventorying important mineral deposits that could be used to meet the food requirements of a rapidly growing population.

2.22. Although only two countries, Zimbabwe and Senegal, produce phosphate fertilizers in any significant quantities, a great deal of effort has gone into the development of alternative strategies for the utilization of the phosphate ores of the region. These alternatives include (1) the use of finely ground rock for direct application; (2) development of granular forms of the rock to improve handling characteristics; (3) combination of the finely ground rock with other materials such as elemental sulfur, manures, and compost; and (4) production of partially acidulated phosphate rock (PAPR) to improve their solubility.

2.23. Of the alternatives listed above, the use of finely ground phosphate rock for direct application appears to have received the greatest attention as this technology requires low input in terms of capital and energy. Several factors, however, affect the use of PR for direct application. Some of these factors are related to the chemistry and mineralogy of the rock, others to the properties of the soil or physiological make up of the crop. We will only briefly summarize some of the work conducted with PR in West Africa.

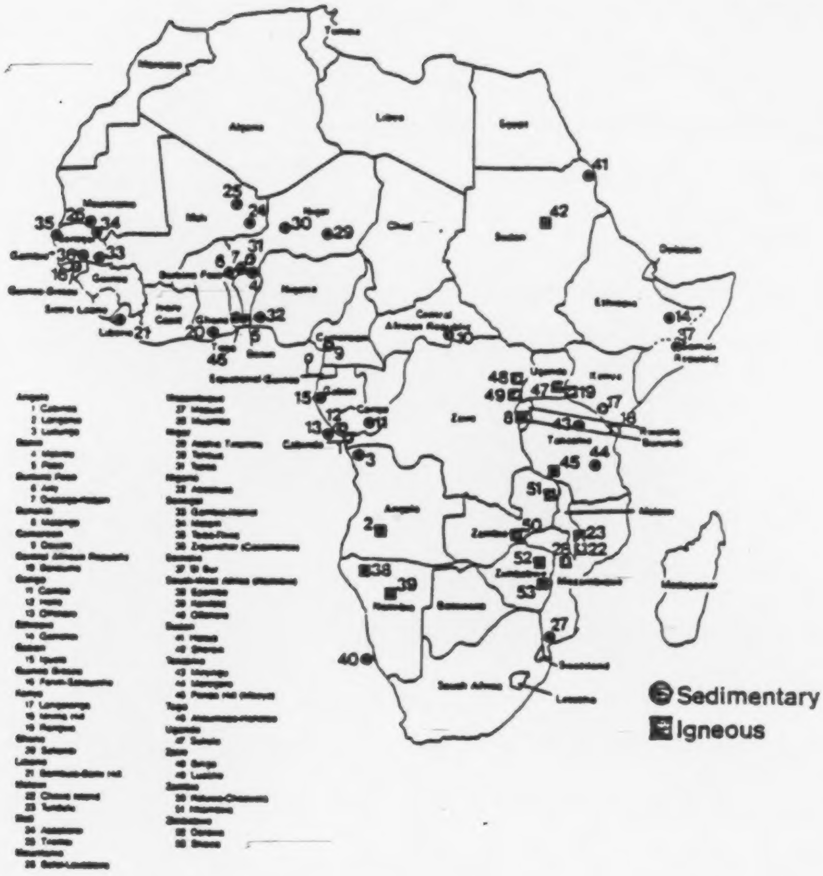


Figure 2.2. Phosphate Occurrences of Sub-Saharan Africa.

2.24. With the exception of the aluminum phosphate deposits in Pallo (near Thies) in Senegal, the principal phosphate mineral in most phosphate rocks in West Africa is apatite. But apatite varies widely in physical, chemical, and chrystallographic properties. These properties in turn determine the agronomic potential of the rock. On the basis of their solubility in neutral ammonium citrate, only Matam (Senegal), Tilemsi Valley (Mali), and Tahoua (Niger) PR could be classified as medium reactive and with potential for direct application. The remaining PRs in West Africa are of low reactivity as reflected in results from field trials (Figure 2.3). For PRs to be used effectively they have to be finely ground. Many rocks in Africa are rich in silica increasing the cost of grinding. Phosphate rocks perform best in acid soils. The low calcium and phosphate contents of acid soils encourage the dissolution of apatite. Soils of sub-Saharan Africa are primarily Ultisols, Oxisols, and Alfisols and, in general, are acid. Recent information suggests that acid soils with high P retention are not particularly suitable for phosphate rocks. Results of trials in tropical Latin America (Hammond et al., 1986) showed that both TSP and PR declined in effectiveness as the P-retention capacity of soils increased, but the PR tended to decline at a more rapid rate. There are soils in the Central and Eastern Highlands of tropical Africa that have high P-retention properties and the use of PR in these soils would be expected to have little potential. Most of the West African soils have relatively low P retention capacity and use of PR in these soils has a higher potential.

STATUS REPORTS

3.1. An inventory of the use of various soil fertility maintenance practices is not available for sub-Saharan Africa. In the following section we will attempt to sketch a picture of their adoption and constraints to adoption based on published information and experience.

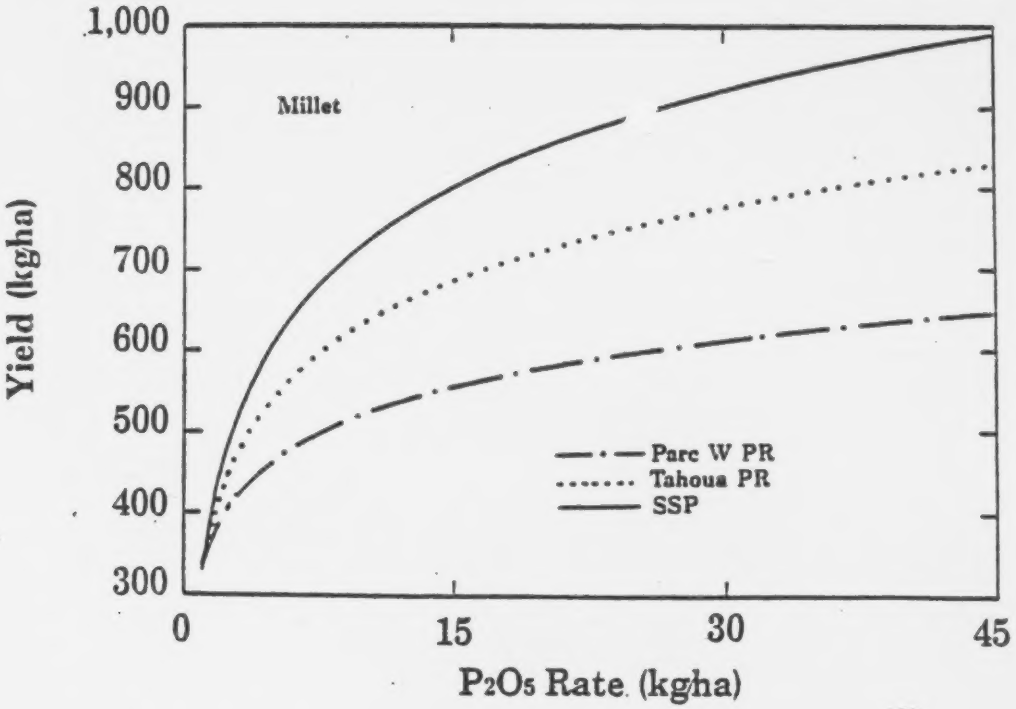


Figure 2.3. Millet Grain Yield Obtained With Two Phosphate Rocks (PR) and Single Superphosphate (SSP) at Gobery in Niger. Adapted From Bationo et al. (1985).

Manures

3.2. The role of farm animals in Africa as compared with other parts of the world is given by Blaxter (1975). Despite the relatively high number of animals per capita in Africa, the use of manure from animals is rather limited, due primarily to poor integration of animal and crop husbandry. On the other hand, the use of household litter on gardens near the home is common throughout Africa. The use of night soil, common in various Asian countries, is virtually unknown in Africa.

3.3. Animal husbandry has been largely impossible in the humid tropical (forest) areas of Africa due to the tsetse fly. Even with promising developments in overcoming trypanosomiasis and theileriasis that primarily affect cattle in Africa, the social and cultural barriers to integrating animal and crop husbandry will take time to overcome. Thus, in this part of Africa where cattle is absent, the scope for manuring is limited (Duncan, 1974).

3.4. In the savannah zones where cattle is present, the use of dung production is limited as a result of the semi-nomadic husbandry practices. Commercial and intensive types of cattle raising are of little importance in most of sudano-sahelian Africa (Poulain, 1974). In general, the cattle is entrusted to a herdsman who moves them around communal land. There is an association between cultivator and herdsman, but no integration. Real integration presumes the use of fallow for fodder and the use of crop residues. Such integration could provide milk or traction to the farm, as well as produce manure, but the constraints in feeding the animals are hampering its acceptance. For instance, in Burkina Faso, the four oxen needed to provide traction to a farm of four active persons would require twice the amount of fodder they could produce on 6 ha of cropland and 2.5 ha of fallow needed to feed the family (Poulain, 1974).

3.5. In the sahelian zone, cattle husbandry is strictly nomadic. Not only is the prospect of collecting dung rather limited, the transport of this material to crop growing areas would pose severe logistic problems and would hardly be economical. Moreover, the wisdom of exporting soil fertility from these fragile lands is highly questionable.

3.6. In the highlands of eastern Africa the potential for integrated crop and animal husbandry is possibly the greatest. In Tanzania alone, the total manure production was estimated in 1978 to be about 11 million tons/year, or the equivalent of 77,000 tons of nitrogen. However, only 11% of the farmers were found to use manure (Kassemba et al., 1983). The majority of the cattle roams during the day limiting the collection prospects (Kyomo, 1983). In countries with high population pressures, the conversion of pastures into croplands is reducing the scope for animal husbandry, and thus the use of manure. In Rwanda it is estimated that a farm with less than 1 ha of land (57% of the farms in that country) is too small to support a cow without purchasing feed. As a result, only one in four farms in Rwanda actually have cows, while only 4% of the farmers stable their cows permanently. It should be pointed out that these minimum land requirements are highly variable and are dependent on agro-ecological conditions. They can be substantially altered by inputs such as fertilizer or irrigation.

3.7. The adoption of manuring practices as a means of soil fertility conservation is not scale neutral. The technology is too costly in land and labor for the smallest farmer who is deprived of storage facilities, traction, transportation, and implements to apply and incorporate the bulky material. On the other hand, in situations where abundant land is available, there will be little incentive to abandon the shifting cultivation practices. Therefore it appears that adoption of manuring stands the greatest chance where the shortening cycle of land use leads to rapidly declining average returns to labor over time (Duncan, 1974). Two other scenarios identified by Duncan as leading to adoption are:

- Where organic fertilizing will contribute to adequate and secure returns from a cash crop.
- Where the cost of organic fertilizers are exceptionally low.

The former condition is met when adequate markets exist for cash crops produced with the necessary infrastructure to move the product, while the second condition requires better integration of crop and animal husbandry.

3.8. The recycling of organic residues has been a major promotional theme of the FAO. For Africa alone, two major seminars were held on the subject (FAO, 1980, 1982). Various other assistance agencies (e.g., IRAT, GTZ, SIDA, USAID) have placed emphasis on organic recycling. However, the introduction of manuring practices is so dependent on local-specific social, economic, and physical factors that these agencies can merely support demonstration projects while leaving the extension aspect to the national programs. Progress to date has been less than impressive.

Biological Nitrogen Fixation and Vascular-Abuscular Mycorrhizae

3.9. It would be difficult to find a farmer in Africa who does not reap the benefits of BNF and VAM in one form or another. Traditional farming systems relied on extended bush fallows to regenerate soil fertility and many native leguminous species spontaneously would infest the abandoned land. In addition, numerous forage legumes are native to the African continent and can be found in wild pastures, more typical for the savannas. However, in these farming systems no effort is made by the farmers to maximize BNF through fallow management. However, many of the traditional cropping systems include a leguminous crop in the rotation (e.g., millet/cowpea and maize/cowpea in West Africa and maize/bean in East Africa).

3.10. In more recent years, a greater awareness of the potential benefits of BNF has caused the introduction of new cropping systems that place more emphasis on the leguminous crops. However, few farmers in Africa can afford the luxury of setting aside land for green manuring or own the implements to turn a green manure under. Scientists are exploring novel means of introducing the green manuring benefits in systems such as agro-forestry and alley cropping with leguminous trees. These cropping systems aspects of BNF will, however, be discussed elsewhere.

3.11. Research is underway in many places to select plant types that will provide greater flexibility in the design of cropping systems, utilizing legumes. IITA, for example has bred short duration cowpea varieties that can be grown in rotation with a cereal rather than as a relay crop. Thus, the yield depression resulting from mutual shading may be eliminated (Figure 3.1).

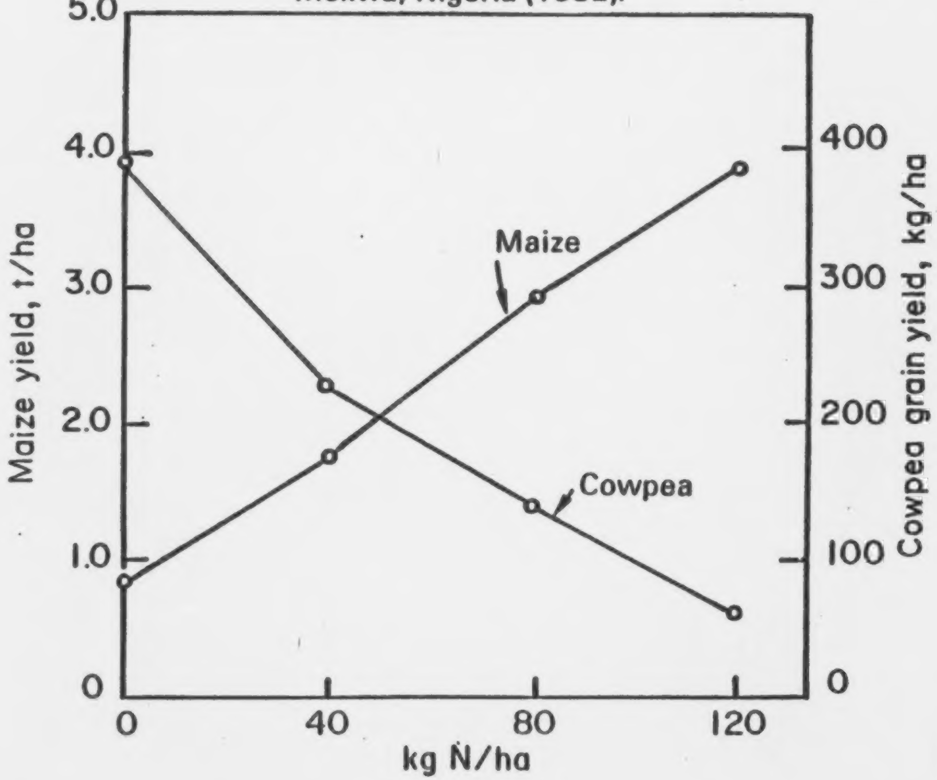
3.12. A drastic increase took place in the acreage under cassava in West Africa when the fallow periods were being shortened with a consequent decline in soil fertility. Cassava is better able to survive low fertility conditions as it depends to a great extent on VAM association to extract what little nutrients there are in the soil.

3.13. The performance of the indigenous species can be improved by better soil management such as the promotion of practices that increase soil pH, increase Ca, and reduce Al and Mn (e.g., liming, use of phosphate rock). The use of VAM inoculant is strictly in a research phase, spearheaded by ORSTOM in Dakar, Senegal.

Indigenous Mineral Resources

3.14. Although currently at least 26 countries in sub-Saharan Africa are known to possess workable phosphate rock deposits, only a few of these deposits

Figure 3.1
Effects of Rates of N on the Cowpea and Maize Grain Yield.
Mokwa, Nigeria (1982).



have been exploited to boost food production. Most of the efforts to encourage the use of indigenous phosphate rock have occurred in Francophone Africa, especially in West Africa. As already noted, apart from the PR deposits from eastern Senegal (Matam), Mali (Tilemsi Valley), and Niger (Tahoua), the known deposits in West Africa are unreactive, as are the deposits of East and Southern Africa.

3.15. Attempts have been made in Senegal, Mali, Burkina Faso, and Niger to provide farmers with phosphate rock at prices lower than imported fertilizer. Unfortunately, use of PR has not become widespread and several reasons account for this. Firstly, in the dry, dusty, and windy environments of the Sahel, application of finely ground PR was an unacceptable chore for the farmer. Research results showed that the degree of fineness of the PR influenced its initial dissolution rate in the soils (Poulain and Mara, 1965). The degree of fineness required was influenced by the moisture content of the soil at time of application and the reactivity of the rock. Secondly, farmers who wanted the full benefit from the PR application were forced to adopt a settled or semi-intensive system of farming to capture the large residual effects up to the fourth crop. Crop rotations had to be developed for this purpose. With problems of land tenure prevalent in most African countries, adoption of these practices was negligible.

3.16. In spite of these shortcomings, there are renewed efforts to increase the use of phosphate rocks, either in their natural state (PR) or slightly modified (PAPR). It is recognized that the less reactive rocks are much less effective than soluble phosphates, yet a remarkable increase in yield is possible with the application of PR. For example, the application of 30 kg P_2O_5/ha of indigenous Parc-W rock in a trial in Niger almost doubled the yield of millet (from 300 kg/ha to almost 600 kg/ha). Similar results have been obtained with Togo rock in many coastal West African countries and with Sukulu PR from Uganda in Kenya (Bationo et al., 1986).

3.17. The dust problem may be overcome by small sized granulation of the fine powders (minigranules) using binders such as KCl, urea, or mineral acids, as proposed by IFDC. The effectiveness of minigranules has been proven in greenhouse and field (Hammond et al., 1987). The adoption of this technology will depend on the cost of minigranulation.

3.18. Use of small portions of the acid needed to fully digest the rocks (partial acidulation) has also led to the production of materials with greatly enhanced initial effectiveness. In several field trials all over tropical Africa (Bationo et al., 1986) it has been shown that 50% partial acidulated products (PAPR) made from unreactive phosphate rocks produced similar yields as the fully acidulated superphosphate. Because there are savings in acid consumption during the production, the products are expected to be cheaper than imported commercial fertilizers. Field trials show that the phosphate requirement to correct P deficiency of most tropical African soils is low, and most soils have low to medium P-retention capacities, characteristics desirable for use of PR or PAPR. In the short run, the potential for use of finely ground phosphate rock, especially in the coarse-textured Oxisols, Ultisols, and Alfisols, is excellent. The fact that most of the rocks of the region are unreactive makes the use of PR a stopgap measure. For the crops to obtain their yield potential, in the long run, more soluble P fertilizers are needed.

THE HOW TO'S

4.1. Table 4.1 provides an overview of the means by which the principles and concepts of OTA can be applied to the technology of soil fertility maintenance. Since most points raised in Table 4.1 are not specific to the soil fertility maintenance issue, they will not be discussed in detail. Three main issues will be elaborated upon below.

Table 4.1. The Application of OTA Principles to Further Technology Application for Sustaining Soil Fertility in Sub-Saharan Africa

Principle A--Systems Approach

To Be Done	How	Who	Limitations
Increase adoption of available technologies	Identify constraints to adoption of organic and mineral fertilizer and beneficial cropping systems	IARC, National programs, universities	Lack of interest and manpower
	Study existing fertilizer sector	IARC, consultants	Lack of funds
Develop a fertilizer sector	Create linkages between Ministries of Agric., Mines, Chemicals and and Fertilizers, Transportation	World Bank, donors Government	Lack of policy
	Train personnel	IARC, universities	
	Strengthen private sector participation in marketing and distribution	World Bank, donors	Government interference high risk
Create effective research and extension program on soil fertility maintenance	Train adequate personnel	Universities, IARCs	Limited supply of candidates due to low appeal of agriculture
	Conduct regular workshops and field tours	National programs with IARC assistance	
	Stimulate farmers' participation in research (on farm)	National programs, FAO	Lack of on-farm researchers
			Inadequate government support for research

(Continued)

Table 4.1. The Application of OTA Principles to Further Technology Application for Sustaining Soil Fertility in Sub-Saharan Africa (Continued)

Principle B--External Linkages

To Be Done	How	Who	Limitations
Increase markets for potential cash crops	Evaluate marketing constraints	IARCs, consultants	Lack of priority
	Develop storage facilities and infrastructure	Donors	Lack of funds and capability at village level
	Improve post-harvest technologies		
Increase credit availability	Provide funds for farmers' credit	World Bank, regional banks	Lack of funds
	Organize credit scheme	National banking systems	Bad experience in repayment
Promote implement manufacture at village level	Provide voc. ed. training opportunities	Donor, national program	Low priority for donors and national program
	Develop extension program on farm tools	Donor, national program	Lack of funds
Integrate farmer and herder to benefit soil fertility	Survey constraints to integration	IARCs, universities	Mandate not assigned clearly
	Study means of compatible integration	IARC, universities	Time delay in payoff
	Conduct pilot programs	National program, donors	

(Continued)

Table 4.1. The Application of OTA Principles to Further Technology Application for Sustaining Soil Fertility in Sub-Saharan Africa (Continued)

Principle C--Minimize Risk

To Be Done	How	Who	Limitations
Promote fertilizer (mineral and organic) without undue risk	Develop government policies (price, subsidies)	National program, donors, consultants	Lack of long-term philosophy
	Implement policies on long-term basis with proper monitoring		
	Test policy impact on pilot scale		
Introduce cropping systems involving cash crops to stimulate cash economies	Study cash crop potential	National program, donors	Lack of stability in prices
	Develop marketing system		
Introduce leguminous crops that have direct or indirect economic value	Develop adaptable varieties of grain legumes	IARCs	Lack of research data
	Promote leguminous trees and shrubs for firewood, shelter belts, and erosion ridges	Donors, forestry dept., ICRAF	

(Continued)

Table 4.1. The Application of OTA Principles to Further Technology Application for Sustaining Soil Fertility in Sub-Saharan Africa (Continued)

Principles D and H--Local Resources

To Be Done	How	Who	Limitations
Develop indigenous mineral deposits for agricultural use	Study and assess potential of resources	IARC, consultants, universities	Lack of funds
	Develop mining/production facilities of economically viable products	Industrial consultants, IARC	
	Develop marketing/distribution system	Consultant/ universities	
Increase use of compost and manure already produced	Develop integrated crop/livestock husbandry systems suitable to physical and social environment	IARCs	Lack of knowledge of social constraints
	Avoid land partitioning leading to exclusion of animal from farm	National program	Population growth rate
	Introduce traction and carts	Extension service	Farmers know-how
Promote use of legumes and azolla	Demonstrate benefits of these indigenous crops	Extension	
	Breed varieties that are better adapted using local and imported germplasm	IARCs	
Study and expand the local knowledge base	Involve or coordinate with national programs and institutions	IARCs	
	Train necessary manpower and strengthen national programs	IARCs	
	Involve farmers at all levels	IARCs, national programs	

(Continued)

Table 4.1. The Application of OTA Principles to Further Technology Application for Sustaining Soil Fertility in Sub-Saharan Africa (Continued)

Principles E and F--Target Neutrality

To Be Done	How	Who	Limitations
Assess differential impact of technology change	Rapid appraisal surveys Develop monitoring systems Test in pilot schemes	IARCs, national programs	Lack of coordination
Institute corrective policies to overcome undesirable discrimination	Concentrate and target extension services Relax credit conditions Adapt technological options Improve services and infrastructure to distant farms (sales points, vet services)	National programs no donor support	Lack of information

(Continued)

Table 4.1. The Application of OTA Principles to Further Technology Application for Sustaining Soil Fertility in Sub-Saharan Africa (Continued)

Principle G--Sustainability

To Be Done	How	Who	Limitations
Assess long-term effects of technology change	Conduct long-term agronomic experiments	IARC, national research programs	Manpower stability
	Allow full assessment of pilot schemes for institutional and social impact	World Bank, ADPs	Funds
Assess effects of mining and production systems	Conduct detailed economic feasibility studies using sustained food-aid as one point of departure	Consultants, IARC	Internal rate of return policies
	Scale production to realistic demands, thinking small and leave options for future	Donors	Investment policies
	Determine need for government involvement	World Bank, governments	Political philosophies
	Conduct environmental and social impact studies	Consultants	Limited concerns

A. Farmers' constraint to technology adoption.

B. Fertilizer sector development.

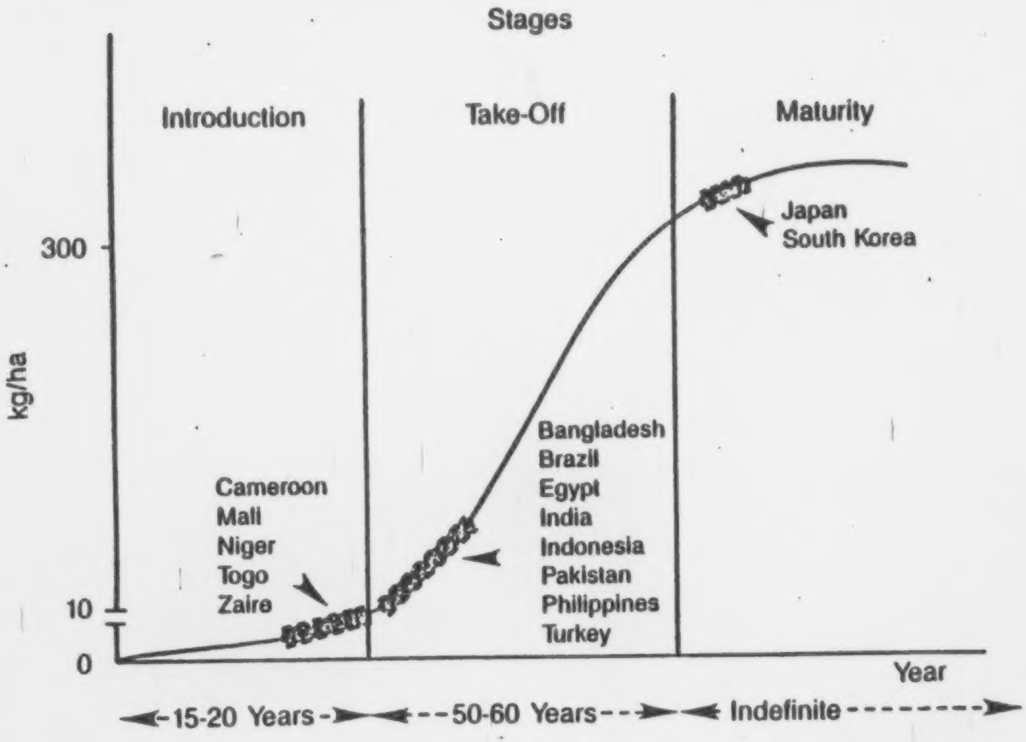
C. Sustainability.

4.2. It is not uncommon that technology developments take place in the protected environment of experiment stations with little regard for the problems facing the ultimate user, the farmer. Fertilizer technology developments with indigenous phosphate rock in Colombia proved successful at the research level but of no benefit to farmers if local cultural practices were maintained. This caused the realization that fertilizers need to be made part of a package that farmers can adopt as a whole (Ashby, 1985). Rapid appraisal surveys to assess farmers' practices and participatory research to test the validity of research findings under farmers' field conditions should be part of a fertilizer research program. Technologies, in order to be improved and relevant as far as the farmer is concerned, have to be compatible with the farmer's resources (natural and human), the support system he is exposed to, and the priorities or goals he has adopted, requiring a two-way communication between research/extension and farmer (Norman, 1985).

4.3. The fertilizer sector in Africa is in its infancy (Figure 4.1). The major stumbling block regarding the sector development is lack of a consistent long-term fertilizer policy. Governments are either ill prepared or unwilling to lay out such policies while donors are providing contradictory advice dependent on their political flavor or national interests. For instance, the policy in Rwanda until 1983 was to de-emphasize fertilizer use. During a 1986 site visit several donors (GTZ and USAID) expressed their adherence to this policy, whereas the country has come to the realization that fertilizers are an essential ingredient for the future and proclaimed 1985 the year of the fertilizers. Other donors (EC, Japan, FAO) have helped to bring about this turnaround. In the

Figure 4.1

Stages of Development of Fertilizer Use in Selected Countries



meantime, the country is still lacking a comprehensive long-term plan for the development of the sector which would involve, among others:

- Training of a cadre of fertilizer personnel.
- Supply strategy (local, regional, or import).
- Distribution and marketing plan.
- Credit and price/subsidy plan.

The ad hoc donation of fertilizers by the western world, although better than food aid, can hardly be considered a long-term solution to Africa's food problems.

4.4. Assessing the long-term impact of a technology change is rarely a high priority in tropical Africa, particularly when food problems are urgent. However, the introduction of western farming practices without long-term evaluations of their usefulness in the African context has led to some poor performances (Eicher, 1986). The introduction of fertilizers, the integration of crop and livestock husbandry, and the changing of cropping systems all may have social, economic, and physical ramifications that are not easily assessed in the short run. Programs (research and pilot projects) should be designed to adequately assess these effects and their desirability.

POLICY

5.1. The policy ramifications of the fertility maintenance strategies discussed so far are primarily related to the use of mineral and organic fertilizer. The policy issue regarding BNF and VAM are primarily cropping system related and are discussed in the subject papers. Therefore, the discussion here will focus on fertilizer issues.

5.2. The fertilizer problems can be divided into two broad categories: (1) fertilizer demand, at both the farm and national levels, is low and fluctuating even when fertilizer is available at the right time and place and (2) fertilizer is not available at the right time and place, and many countries are unable to meet even low fertilizer demand and reduce fluctuations in supply over time.

Most countries in sub-Saharan Africa are facing both demand- and supply-related problems (Mudahar, 1980; Zalla et al., 1977). Since in many of the sub-Saharan African countries the level of and growth in fertilizer use are extremely low, it is important to identify and analyze fertilizer demand-related problems and policy measures. This paper focuses on demand-related problems and policies. The factors contributing to low fertilizer demand include (1) low fertilizer response, (2) high fertilizer cost, (3) low crop prices, (4) high risk of losing money as a result of the variability in fertilizer response and prices, (5) lack of cash or credit, (6) lack of knowledge, and (7) lack of complementary farm inputs such as fertilizer-responsive crop varieties, water, and insecticides.

5.3. The farmer is the ultimate decisionmaker with respect to fertilizer use and the target of most fertilizer policies. Consequently, it is important to understand the farmers' decisionmaking process regarding fertilizer use and to evaluate the economic implications of alternative fertilizer policies. The knowledge about fertilizer response forms the basis for the economic analysis of fertilizer use which, in turn, forms the basis for fertilizer policy formulation. Given the fertilizer response function, the optimum level of fertilizer use is determined by economic factors, including constraints and risk associated with fertilizer use. Farmers in sub-Saharan Africa frequently face serious environmental constraints. Furthermore, the desire to meet household food consumption needs and to minimize the risk of losing money is extremely important. Most African farmers also tend to face a serious labor constraint, especially during the peak season. Given these considerations farmers will use fertilizer only if its use is economical.

5.4. The selected fertilizer response coefficients from FAO demonstrations are summarized in Table 5.1. These results indicate that yield response to applied fertilizer is positive and significant, and it varies from one crop to another and from one location to another. The fertilizer response is generally higher for export crops, root crops, and those using improved farm practices than for cereals (except possibly for rice) and other crops using traditional farm practices. The variability in fertilizer response for a particular crop is extremely high from one location to another and from one year to another on the same location. There is a need to reduce this variability, and hence the risk factor, through appropriate fertilizer technology and management practices.

5.5. According to FAO, farmers will not use fertilizer if the average value/cost ratios (value of additional crop output due to fertilizer use divided by cost of additional fertilizer use) are lower than 2. For sub-Saharan Africa the minimum acceptable value/cost ratios have to be even higher. In addition to the fertilizer response coefficient, value/cost ratios are determined by three important variables: fertilizer price paid by the farmer, crop price received by the farmer, and associated fertilizer costs (such as labor cost and credit cost) borne by the farmer. The average value/cost ratios based on selected fertilizer response studies in sub-Saharan Africa are reported in Table 5.2. The results indicate that the average value/cost ratios vary from one nutrient to another, from one crop to another, and from one location to another but are generally higher than 2. The value/cost ratios are higher for export crops than for food crops, higher for improved farm practices than for traditional practices, and higher for subsidized fertilizer prices than for unsubsidized fertilizer prices.

However, one must keep in mind that the value/cost ratios are generally based on fertilizer response coefficients from experiment stations and official

Table 5.1. Fertilizer Response Coefficients Based on Fertilizer Demonstrations in Sub-Saharan Africa[a]

Country	Kilogram of Crop Yield Per Kilogram of Applied Nutrients for[b]					
	Sorghum	Maize	Rice	Wheat	Yams	Groundnuts
Botswana	3.8	4.9	-	-	-	-
Cameroon	-	9.8	-	-	49.4	9.1
Ethiopia	16.3	15.1	-	7.3	-	-
Gambia	-	-	6.6	-	-	14.7
Ghana	7.9	11.9	9.4	-	69.0	7.5
Ivory Coast	-	10.3	6.2	-	26.4	-
Kenya	-	14.6	-	-	-	5.0
Nigeria	-	9.5	7.1	-	6.8	15.5
Senegal	-	-	3.7	-	-	6.3
Sierra Leone	-	-	10.3	-	-	7.9
Togo	7.0	6.5	15.2	-	26.8	4.6

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a. Mudahar 1980. The coefficients are based on data reported in FAO 1974.

b. The fertilizer productivity is based on average best NPK treatments between 1961 and 1971.

Table 5.2. Average Value/Cost Ratios Based on Fertilizer Trials in Sub-Saharan Africa[a]

Country	Crop	Average Value/Cost Ratios for[b] N	P_2O_5	K_2O	NPK
Cameroon	Maize	2.2	0.9	2.6	1.9
Ghana	Maize	2.1	2.3	5.8	3.4
Ivory Coast	Maize	1.6	1.2	1.2	1.3
Nigeria	Maize	0.9	0.8	2.2	1.3
Ghana	Rice	5.1	4.8	9.2	6.4
Ivory Coast	Rice	1.8	1.4	2.5	1.9
Nigeria	Rice	2.5	3.1	3.8	3.1
Senegal	Rice	2.8	1.6	5.5	3.3

a. Mudahar 1980. The value/cost ratios are derived from summary results reported in FAO 1974 which are based on average best NPK treatments between 1961 and 1971.

b. The average value/cost ratios are based on the official fertilizer and crop prices.

fertilizer and crop prices; they do not incorporate associated fertilizer cost. Fertilizer response on farmers' fields is lower than that on experiment stations. The fertilizer price paid by the farmer is generally higher than the official price, and the crop price received by the farmer is generally lower than the official price. In addition, the farmer also bears other costs associated with fertilizer use. Consequently, under farmer circumstances the average value/cost ratios may not be as attractive as they appear.

5.6. The possibilities for improving fertilizer use incentives through price policy do not appear very good. Fertilizer subsidies are very common in most sub-Saharan African countries. The stated primary purpose is to lower the fertilizer price paid by the farmer. However, the financial burden of fertilizer subsidies is rather high and increasing over time. Most governments are in the process of reducing fertilizer subsidies by increasing fertilizer prices. In the absence of any significant improvements in fertilizer production, procurement, and marketing efficiences, the prices paid by the farmers are expected to increase.

5.7. Despite temporary slowdown, the energy prices will continue to put an upward pressure on fertilizer prices through an increase in production, marketing, and freight costs (Mudahar and Hignett, 1982). The crop prices, on the other hand, are not expected to increase as rapidly as the fertilizer prices. This is due to inefficient crop marketing systems and the continuous desire of national governments to keep a lid on food prices through so-called cheap food pricing policy. The net result of these pricing policies will be to stop or reverse the declining trend in fertilizer/crop price ratios. This will lower incentives to expand fertilizer use and may dampen fertilizer demand.

In addition, many countries in sub-Saharan Africa (Niger, for example) are reducing or eliminating provision of fertilizer credit because of the high cost of subsidized and poorly implemented credit policies. There is a need for fertilizer credit, but it should be given at a market rate of interest to reduce its inefficient use. Alternatively, fertilizer sales on credit could be linked with crop marketing, i.e., farmer could repay the fertilizer loan at the end of the crop season from receipts of crop sales. This idea has been successfully tried by cooperatives in several Asian countries. Private traders, who are also fertilizer dealers, often practice such a sales strategy.

5.8. Fertilizer promotion must be based on scientific information developed through fertilizer-related agronomic and soil fertility research and sound economic and policy analyses. The fertilizer promotion policy should include development of soil fertility maps, establishment of soil testing laboratories, formulation of soil- and crop-specific fertilizer recommendations, and initiation of well-designed fertilizer demonstrations under farmers' field conditions. At present, fertilizer recommendations for specific agroclimatic conditions, crops, crop technology, and soil conditions generally do not exist. The blanket recommendations for the whole country are not only inappropriate but could in fact be counterproductive.

The productivity of fertilizer use is heavily influenced by fertilizer management. Many countries in sub-Saharan Africa do have agricultural extension agencies of some sort that are assigned the job of fertilizer promotion and its efficient use. In many countries, the total expenditure on agricultural extension is larger than the expenditure on agricultural research, clearly indicating misplaced priorities (Boyce and Evenson, 1975). There is a need not to reduce the expenditure on agricultural extension but rather to substantially increase the expenditure on agricultural research.

5.9. Most countries in sub-Saharan Africa depend on imports to meet part or all of their domestic fertilizer requirements. Fertilizer imports generally do not receive the priority or timely allocation of foreign exchange which is rather scarce. However, most countries do have phosphate resources that could be used to produce modified phosphate fertilizers, especially PAPR which has been found to be as economical a source of P_2O_5 as SSP. Furthermore, the use of indigenous phosphate resources through PAPR or other modified phosphate fertilizers not only saves foreign exchange and provides phosphate fertilizer security but also has many other direct and indirect potential economic benefits for the country over imported SSP.

5.10. The known reserves of phosphate rock (at current prices and technology) in most sub-Saharan countries are small by world standards. However, these reserves are large enough to meet phosphate fertilizer requirements of individual countries for decades. The phosphate resources vary in chemical composition, and many are known to have impurities. As a result, the small quantity along with poor quality precludes the use of many of these phosphate resources for manufacturing known commercial phosphate fertilizers. However, many of these resources may have a place in low-resource agriculture, either for direct application or for manufacturing modified phosphate fertilizers such as partially acidulated phosphate rock (PAPR).

5.11. The use of plant residues, manures, or compost as a means of conserving soil fertility should be promoted by national programs and donor agencies alike. However, the integration of crop and livestock husbandry is a dramatic change in farming systems for most of sub-Saharan Africa. The research and extension effort devoted to this aspect in the various agro-ecological zones where integration is potentially feasible is far too little to bring about this change.

5.12. The soil fertility constraints in Africa are rapidly becoming recognized as one of the principal obstacles to sustained crop production. The means to alleviate this constraint will require a concerted research effort to be developed. It appears timely for donors to re-evaluate the fragmentary approach to soils research in Africa, and to create an organizational structure that will orchestrate the research needed to ensure soil fertility maintenance in the different agro-ecological zones, and study the physical and socioeconomic consequences of the different strategies. This organization should also address the manpower requirements of sub-Saharan Africa in the area of soil science in order to ensure the emergence of strong national programs to conserve this critical resource.

5.13. The role of mineral fertilizers in soil fertility maintenance is considerable. The support from the donor community for the establishment of a sister institution of IFDC in Togo could go a long way in helping the establishment of a fertilizer sector in the region by:

- Developing a regional research program for fertilizer use.
- Assisting countries in the development of indigenous resources for fertilizer use.
- Strengthening national fertilizer sectors through technical assistance.
- Training the manpower needs for the fertilizer sector. The annual additional technical manpower requirements in sub-Saharan Africa over a 20-year period (from 1982/83 to 2002/03) are about 1,600 persons for the fertilizer sector, including fertilizer production, marketing, and use.

TECHNOLOGY POTENTIAL

6.1. The potential benefits for substantial additional contribution from BNF and VAM are awaiting a breakthrough in their technologies. Their benefits can be optimized through selection of alternative cropping systems incorporating leguminous crops or azolla and VAM hosts, or by providing soil conditions promoting VAM and BNF. In the arid and semiarid environments of tropical Africa, both water and soil phosphorus may be limiting BNF (Dommergues and Ganry, 1986). The limitations in other environments are varied. It is expected that the benefits from BNF and VAM will play a more important role in African agriculture in the future than it already is, due mostly to the improvements in soil management, cropping systems, and host crop selection.

6.2. The potential benefits of organic recycling in Africa are substantial. The role of animals in this process is still dubious and may be subject to change as the demographic pressure on land changes. Nonetheless, the rate of nutrient export can be reduced by as much as 50% of crop residues are left in place or returned. The fact remains that much of the crop residue in Africa is considered of value and is used for fuel, building material, or cattle feed. With the fallow periods shortening, the most promising route appears to be continuous green manuring in agro-forestry or alley cropping types of systems. The potential for such systems is discussed elsewhere.

6.3. The potential for fertilizer use as a means of alleviating the food problems of sub-Saharan Africa is excellent, provided the many constraints can be overcome. The situation in Africa is more or less comparable to that of southeast Asia in the sixties. Fertilizers have played a major role in agricultural development in that region. The indigenous resources of Asia are increasingly being exploited to eliminate import dependency. Although fertilizers alone can change the production potential of tropical Africa in a similar fashion, various accompanying changes can boost their impact dramatically.

6.4. As risk aversion is a major concern, fertilizer will not likely be applied in the absence of an assured water supply (from rainfall or irrigation) even if fertilizer-responsive crop varieties are available. An assured supply of water facilitates the use of modern farm technology and multiple cropping, and reduces yield risk with or without modern farm technology. Many countries in sub-Saharan Africa have no irrigation systems or only poorly developed ones.

For example, in 20 of 34 sub-Saharan African countries less than 2% of the arable land is equipped for irrigation, regardless of the quality. The development of an irrigation system is very expensive and requires a long time. The prospects of a rapid expansion in irrigated area in the next decade are rather limited in sub-Saharan Africa.

6.5. In addition to developing the necessary infrastructure and institutions that serve the agricultural and fertilizer sectors, there is a need to increase resources for agricultural research. According to Saouma (1986), land and water degradation is a critical problem. Cropland is being overexploited, rangelands overstocked, and forest cut down. Low soil fertility, especially in West Africa, is an example of a problem that requires sustained basic research. Several scientists claim that what is needed in Africa is an international soils research center to carry out basic scientific research on the causes of low soil fertility, which over a period of 10-15 years may require an operating budget of as much as $100-$150 million (Eicher, 1986). The experience around the world indicates that returns to investment in agricultural research are very high (Ruttan, 1982). Agricultural research in sub-Saharan Africa needs to be directed toward crop improvement in the context of both existing and improved farming systems. The objective of crop improvement research must be to develop crop varieties that are high yielding, fertilizer responsive, disease resistant, pest resistant, drought resistant, and suitable for local environmental conditions. In this context, very limited progress has been made in sub-Saharan Africa. It should be kept in mind that modern crop varieties in the absence of fertilizer use may not yield any more than do the existing crop varieties.

6.6. One of the major problems facing sub-Saharan Africa is the pursuit of economic policies that discriminate against the agricultural sector. This includes agricultural price policy, taxation policy, trade policy, technology policy, marketing policy, and policies designed to provide basic amenities to the rural population. With the exception of oil- and mineral-exporting countries, the agricultural sector contributes a major share to the GDP. Yet the share of national public expenditure allocated to the agricultural sector is extremely small (Mudahar, 1986). Such a strategy reflects government's lack of commitment to develop the agricultural sector and raise the income levels of the rural poor.

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UNREVISED DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

OTA TECHNOLOGY PAPER SERIES: CROP ROTATION AND RESIDUE MANAGEMENT

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ABSTRACT

Manual land clearing, mulch farming, conservation tillage, agroforestry, cover crops, mixed cropping, and early sowing are important technological innovations for improved and sustained productivity in tropical Africa. Improved technologies for humid equatorial and coastal lowlands, include manual land clearing, perennial and root crops based systems, liberal use of mulch and cover crops, and conservation tillage. In subhumid tropical upland, and semi-arid regions, vegetation should be preferably removed manually or by shearblade. Chain clearing is more appropriate in the development of savanna lands. Sowing cover crops for one to two years is essential if mechanized clearing is unavoidable. Grain crops should be grown with no-till or conservation tillage systems. Appropriate crop combinations are cereal plus cassava or cereals plus legume mixtures. Soil fertility can be maintained by agroforestry, cover crops and the use of mulch and compost. Early sowing is an essential factor for high and stable yields. Insufficient water availability is the critical factor in arid regions. Small scale irrigation should be developed to provide supplementary irrigation. Agroforestry is useful especially when it involves the use of native tree species.

Much of the agrarian stagnation in Africa is caused by the neglect and misuse of natural resources. The root cause of low production and famine lies in misuse of soil and water resources. Priorities lie in both short-term development projects on the basis of proven and validated technologies and in initiating long-term research to understand soil and water resources and in learning how to live with them. Agricultural research must address the issue of improving the welfare of resource-poor farmers. Africa has a potential to be food self-sufficient and this potential is realizable if the right options are chosen and the right approach adopted to research and development.

INTRODUCTION

1. Sub-Sharan Africa covers a land area of 22.2 million km^2 on which about 400 million inhabitant live with a per capita GNP of US $235 to 436 and with a mean life expectancy of less than 50 years (La-Anyane, 1985; Levi and Havinden , 1984; MacNamara, 1985). The sub-Saharan Africa has the highest population growth rate in the world i.e. 3.2% per year, doubling the population every 22 years. Consequently, the growth rate of per capita food production in this region has been 1.0, -1.2 and -2.0 percent respectively for decades ending in 1970 and 1979 and the five year period ending in 1984. The over riding concern is what are the factors responsible for this decline and how to reverse the trend?

2. The recurring drought, perpetual food deficit and the agrarian stagnation in tropical Africa have been caused by the neglect and misuse of natural resources over a long period of time. It is the

utter disregard of the potential and constraints of the natural resources that is responsible for the gross imbalance between soil, food and population. This neglect cannot continue indefinitely without paying the heavy price in terms of human suffering and low standard of living. The development of long range research and development strategies for improving productivity of individual farm households is an urgent priority.

3. Although the emergency food aid will be required to abate mass starvation for sometime to come, priority lies in both short-term development projects on the basis of proven and validated technologies and in initiating long-term research to understand the soil and water resources and to determine how to manage them. While institution building and development-related activities are relevant, it is important to build the data base that will provide basis for management options and sustainable alternatives. The research base thus developed will provide the safeguard against the dangerous and undue reliance now being placed on importing land management technologies from other continents rather than on generating them locally within the different agro-ecological regions of Arica. The resource-management research will address the issue of increasing productivity on marginal lands and in harsh environments without depending heavily on purchased inputs.

CLIENT AND THE TECHNOLOGICAL OPTIONS

Sub-Saharan agriculture is characterized by small-scale, resource-poor farmers. Improvements in such agriculture are to be sought on the basis of the locally available inputs and other renewable resources. The inputs not available to a majority of resource-poor farmers include agro-chemicals (e.g. fertilizers, insecticides, fungicides and herbicides), farm power, and motorized equipment. The management options have to consider the nutrient-deficient soils, erratic and unpredictable rainfall, and limited potential of expanding irrigation facilities. Under these situations, the improved technology is to be evaluated by a multiple set of system-performance indicators - productivity, stability, sustainability and equity. The traditional farming techniques have low productivity. The improved systems must have both high productivity and high stability, and low risks. Suitable technologies, therefore, have to be the resource-efficient technologies. For example, varieties and cropping systems must be developed that are tolerant to pests and that can maintain economic yields at low levels of soil fertility. Similarly, the soil management systems are to be such that minimize dependence on agro-chemicals and preserve the natural resource. The objective is not to develop a system that produces the best yield in a good year but the one that produces stable yield even in a bad year.

SOILS AND EXISTING FARMING SYSTEMS

5. Soils in tropical Africa can be described under three general groupings: (i) highly weathered soils with low activity clays (ii) moderately weathered soils derived mainly from basic rocks and volcanic materials and (iii) hydromorphic or alluvial soils.

6. The highly weathered soils mostly occur in humid and sub-humid tropical uplands and comprise mainly Oxisols, Utisols and Alfisols with low activity clays. These soils occupy about 71 percent of the total land area in the humid equatorial and coastal lowlands regions. These soils have low cation exchange capacity, low plant nutrient reserves, low available water holding capacity, and are highly susceptible to erosion. In addition, most Ultisols and Oxisols are strongly acidic and phyto-toxicity of Al is a problem for an intensive food crop production system. Less weathered soils (Mainly Andepts, Mollisols and some Alfisols) are those derived from volcanic ash and basic and ferromagnesian rocks and are important soils for the highlands. Soils derived from volcanic ash are fertile and possess favorable soil properties. These are agriculturally important soils in Western Cameroon, Rwanda, Burundi, Kivu region of Zaire and in parts of Eastern Africa. These soils support the most productive plantations of perennial crops e.g. coffee, tea, banana etc.

7. Predominant soils of subhumid tropical uplands are Alfisols, Psamment, and Inceptisols. Alfisols are comparatively fertile and less leached but are highly prone to compaction and accelerated soil erosion. Most Psammentic soils are coarse-textured and of alluvial origin. These soils are deficient in both major and micronutrients, are prone to frequent drought even during the rainy season, and are susceptible to erosion. These soils are often underlain by hardened plinthite at shallow depths and have, therefore, a shallow effective rooting volume.

8. Agriculturally important soils of the semi-arid regions are Alfisols, Inceptisols, Aridisols and Vertisols. Alfisols occupy about

50% of the land area in semi-arid regions. Alfisols are prone to crusting, compaction, accelerated soil erosion and frequent drought stress. In contrast to soils with predominantly low-activity clays, Vertisols contain high percentage of high activity clays. Vertisols, covering 63 million hectares in semi-arid Africa, are difficult to manage. The range of moisture content for good workability is narrow because of poor trafficability of Vertisols during the rainy season. Vertisols are highly susceptibly to accelerated erosion and have low infiltration rate.

9. Soils of the arid region, generally grouped as Aridisols, are improverished and are prone to severe wind and water erosion. Overgrazing has been partly responsible for severe degradation.

EXISTING FARMING SYSTEMS

10. Generally throughout tropical Africa much of the land is owned communally but temporarily allocated to family units. Each family may work as many as a dozen small plots on soils of varying quality. Subsistence farming is the rule.

The predominant farming systems of all agroclimatic regions of tropical Africa are based on shifting cultivation and related bush fallow systems with a minimal reliance on added inputs. The length of the fallow period differs among soils and crop types. This is essentially a resource-based agriculture practiced by the resource-poor small-scale land- holders. The fertilizer use in sub-saharan Africa range from 2 to 10 kg/ha (FAO, 1986, IFDC, 1985). About 50% of this fertilizer is used for food crops production. Nomadic herding is a common way of life in the semi-arid and arid regions of tropical Africa, and mixed cropping is common in all agro-ecological regions (Okigbo, 1978). 11. Traditional farming systems are labor-intensive and rely mostly on natural resources. With increasing population pressure, traditional farming systems are beset with following challenges: (i) low fertility soils vulnerable to accelerated erosion and degradation, (ii) water availabilty either excessive, insufficient, erratic or undependable, (iii) small and fragmented farms, (iv) non-availability of inputs and (v) lack of infrastructure including limited marketing and transport. A serious problem facing agriculture is the dismal farm policies that have been discriminating against agricultural sectors for decades.

TECHNOLOGICAL OPTIONS

12. Effective land management systems and technologies are crucial to overcoming the misuse of soil that is at the heart of many problems related to agricultural production. The solution lies in controlling landuse and restoring its productivity. This is achievable through innovative technological options already available and awaiting implementation. Although general principles may be the same, technological options differ widely among soils and agro-ecological regions. A logical approach is that of eco-development. This approach considers evaluation of the technical production potential on the basis of basic research data on soils and environments. Alternative management options are then developed and validated locally to realize this potential. Imported technologies developed elsewhere are rarely successful. A useful characteristic of the eco-development approach lies in its consideration of the

interaction between biophysical environment and socio-economic factors of the production process.

A. HUMID EQUATORIAL AND HUMID COASTAL LOWLANDS

13. Major constraints to intensive food production in the humid regions are low soil fertility and nutrient imbalance, accelerated soil erosion and harsh environments, unproductive cropping systems and traditional technologies geared to subsistence rather than commercial agriculture. The existing forest vegetation is cut manually, burnt in-situ, and a mixture of crops are grown through the uncultivated soil. Food needs are met primarily by systems based on cultivation of root crops (cassava, yams) and plantain grown in association with perennials. These crops are grown with little or no purchased inputs.

14. Improved sub-systems or technologies geared to continuous and sustained production imply maintaining soil physical, nutritional and biological properties similar to that under tropical rainforest: (i) undisturbed soil surface, (ii) continuous supply of organic matter to the soil as mulch, (iii) favorable soil temperature and moisture regimes, (iv) high biotic activity of soil fauna, and (v) minimum losses by runoff, erosion or deep leaching. Much of this can be achieved through supplying an adequate amount of organic matter to the soil surface as mulch. Some relevant agricultural technologies that meet these requirements are described below:

15. (i) **Land clearing and development:** Research in West Africa (Lal and Cummings 1979, Lal, 1981, Hulugalle _et al._, 1984; 1986; Lal _et al._, 1986) and in South America (Seubert _et al._, 1977) has indicated definite advantages of manual over machine clearing.

Experiments conducted at the International Institute of Tropical Agriculture (IITA) and the United National University (UNU) near Benin City, Nigeria have shown that if machine clearing is absolutely essential, clearing with shearblade is better than clearing with dozerblade, tree pusher or root rake. The use of root rake should be avoided at all costs because of the excessive soil disturbance it creates. Soil compaction and risks of accelerated soil erosion following shear blade clearing can be avoided by seeding an appropriate cover crop to improve soil physical properties. Land development following land clearing should be kept to a minimum. The thin top soil layer should not be scraped, compacted or mixed with the infertile and acid subsoil. Erosion control is better achieved through biological measures than engineering structures. If needs arise, however, the biological systems of soil conservation may require backup support through strategic installation of diversion channels or grassed waterways.

The manual clearing can only be adopted by small and medium-sized farms. Labor requirements can be prohibitive for large-scale clearing.

16. (ii) **Cropping systems:** Perennial crops are the most logically suited for this ecology. Plantation crops e.g. oil palm, rubber, cocoa can be grown on manually cleared land without further seedbed preparation. Soil and water conservation and fertility maintenance is better achieved through growing a cover crop between the widely-spaced rows of trees. Regular pruning of the cover crop is essential to minimize competition. Food crops can also be grown inbetween the trees during the initial stages of tree establishment.

Seasonal crops should be grown with appropriate cultural practices so that growth of perennial crops is not suppressed.

Appropriate plantation crops for highlands are tea and coffee. Experiments conducted in eastern Africa have shown that mulch farming techniques are the most appropriate for controlling water runoff and erosion (Othieno, 1975; Othieno and Laycock, 1977), and increasing production.

17. In the high-rainfall tropics, plantains and bananas (Musa sp.) are at last equally as important as roots and tubers as major carbohydrate staples. The bananas behave as perennials under the most common production systems, and with good management have through ratooning, remained productive for many years. By frequently adding crop residue mulch the productive life span of plantain is extendable to 4 years. Mulching significantly increases plantain yield (Swennen and Wilson, 1984). Other seasonal crops can be grown in association with plantains as intercrops. Most compatible intercrops with plantains are maize, yam and cocoyam.

18. Root crps e.g. yam (Dioscorea sp.), cassava (Manihot esculenta), sweet potato (Ipomea batata) and taro (Colocassia sp.) are also suitable crops for this region. These crops can be grown in association with perennials or annuals. A suitable grain crop for this region is upland rice.

19. (iii) **Tillage methods:** Conservation tillage, which involves seeding through a crop residue mulch or sod without plowing, has definite advantages in conservation of soil and water, lowering the maximum soil temperature and in maintaining high levels of soil organic matter content. Experiments conducted on yam and cassava on

an acidic Ultisol in eastern Nigeria have shown definite yield advantages of growing root crops using crop residue mulch of 6 to 8 ton/ha (Table 1). Maduakor _et_ _al_., (1984) also observed a yield increase of 5 to 10 percent in yam tuber by mulching in Ultisol near Port Harcourt in the humid coastal lowland regions.

20. (iv) **Fertility Maintenance:** It is a general belief that establishment of perennial crops, plantations and man-made forests following the removal of tropical rainforests is an ecologically better alternative than arable landuse because the latter causes less decline in soil structure and lessen the risks of accelerated soil erosion. _Cassia_ _siamea_ and other fast growing trees establish very well in acid soil conditions. Agroforestry systems based on growing food crop annuals with perennial hedgerows of _Flamingia_ _congesta_ and _Cassia_ _siamea_ are also feasible. Plantain are profitably grown in combination with _flamingia_ _congesta_. Coconuts are often grown in association with grazed or ungrazed pastures.

However, the contention that the restorative effects of forests and of agroforestry practices can provide a total solution to degradation is an over-generalization. With improper management, severe soil compaction, accelerated soil erosion and land degradation are also observed under plantation crops (Lundgren, 1978). A decrease in soil chemical fertility can also occur under perennial crops and man-made forests in comparison with the natural forests. It is difficult to imagine that even with agroforestry and forestry systems, one can go on harvesting the nutrients in agricultural produce without causing a decline in already meagre nutrient capital of the soils in the humid tropics. With good management, however, the chances of achieving economic success and ecologically compatible systems are better with perennials than annual crops.

21. There are important socio-economic and practical barriers in adopting mulch-farming technologies. The mulch material, to be applied once or twice a year at 4 to 6 t/ha, is often not available. If available, it is required for other equally important uses e.g. fuel, folder for goats and small ruminants, and as roofing material. Farmers are reluctant to grow an uneconomic cover crop after investing heavily in forest clearing and in new land development. Cover crops can also provide habitat for diseases and pests that attack crop during the growing season.

Whereas education of farmers and extension agents towards the benefits of mulch farming and growing cover crops will be useful, it is also important to research new systems that provide for alternative uses of mulch materials. Agroforestry and man-made forests based on native fast-growing species are important research considerations. Research is also required in selecting appropriate leguminous cover crops that impove soil fertility, produce a large amount of biomass, but also have some economic returns.

B. SUBHUMID TROPICAL UPLANDS

22. Soils of this zone are of relatively high fertility. The management principles are the same as for the soils of the humid regions. However, grain crops e.g. maize (Zea mays), cowpea (Vigna unguiculata)and soybean (Glycine max) are better suited for this ecology than for humid regions. Some proven technologies are described below:

23. (i) **Land clearing and development:** The removal of vegetation cover by any method can cause deterioration in soil physical and nutritional properties. As a general rule, the use of heavy machinary should be avoided for land clearing. Soil erosion and water runoff are less with those methods that cause less soil disturbance. Watershed management studies conducted at IITA have showen that water runoff and soil erosion were the least with manual methods and land clearing (Table 2). Soil's total and macroporosity are also more with manual than with motorized land clearing techniques. If mechanized land clearing is unavoidable, it is important that a cover crop is planted immediately to alleviate soil compaction and reduce the risks of soil erosion. Hulugalle et al., (1986) observed that immediately seeding with Mucuna utilis increased macroporosity and infiltration rate and decreased soil bulk density and penetrometer resistance (Table 3). Additional soil conservation measures are usually not requird if seasonal crops can be seeded through the chemically or mechanically suppressed sod without any seedbed preparation.

24 (ii) **Mulch farming:** Mulch farming is one of the most appropriate soil management systems for sub-humid upland. Applied 4 to 6 t/ha crop residue mulch can effectively control soil erosion on slopes of up to 15 percent (Lal, 1976). The effectiveness of crop residue mulch, however, depends on soil properties, predominant slopes and the frequency and intensity of rains. Mulch regulates soil temperature and moisture regimes, prevents crusting and soil splash, increases macroporsity by enhancing the biological activity of soil fauna, improves soil organic matter content and increases crop yield

(Lal, 1975; 1986). Alternative cultural practices of procuring crop residue mulch are outlined in Table 4. Most of the cultural practices are site-specific. Therefore, regional validation of these techniques is essential for different soils and agro-ecological regions.

25. (iii) **No-till farming and conservation tillage:** The objective of seedbed preparation is to optimize soil and micro-climate environments in the seedling zone for seed germination and seedling establishment, and minimize competition with weeds. In the long run, the method of seedbed preparation so adopted should also conserve soil and water resources and sustain economic returns. The specific soil-related constraints can be alleviated through appropriate methods of seedbed preparation. The appropriate methods, however, differ among soils and rainfall regimes (Fig. 1), (Lal, 1985). The coarse-textured soils of the humid and sub-humid regions can be adequately managed by no-till farming. If weeds are adequately controlled, satisfactory yields are obtained for most grain crops. For poorly drained and compacted soils, however, crop yields with no-tillage may be sometimes less than with mechanical methods of seedbed preparation. However, the yield per unit input, unit land area and unit soil degradation is generally more with no-till than with plow-based systems of seedbed preparation. The no-till system is not effective for all soils and crops. Crop establishment with the no-till system is generally unsatisfactory on soils that have compacted and crusted surfaces and that have inadequate amount of crop residue mulch.

26. Appropriate tools for seeding through mulch have been developed at IITA and elsewhere. Improved hand-powered tools are more

efficient for no-till farming than traditional hoe and machette. These tools can allow a farm family to grow 5 hectares of grain crops with no additional power added to the farm.

27. (iv) **Cover crops:** In situ production of mulch materials can be achieved by planted fallows e.g. Stylosanthes, Pueraria, Centrosema, Psophocarpus, and Mucuna. One of these crops grown once every three to four years is an important component of animproved cropping system. Quick-growing legume covers provide large quantities of mulch, suppress weed growth, improve soil structure and enhance crop yields (Lal et al., 1979; Wilson et al., 1982). Once desirable cover has been established, seasonal crops can be sown through the mulch of cover crops by suppressing them through chemical or mechanical means.

28. Many researchers (Pereria et al., 1954, Wilkinson, 1975) have shown that benefits of cover crops are lost by the end of first cropping when primary and secondary tillage operations are used. Deterioration of soil structure and infiltration rate during the cropping phase can be drastically reduced by managing the fallow cover through a no-tillage system. A live mulch system is based on the same principle as growing perennial crop in association with a cover crop. A low-growing cover crop is grown specifically to provide a continuous ground cover. Once established, a small strip is opened, with or without using herbicides, to seed a seasonal food crop through it (Akobundu, 1980, 1982). The system works only if the fallow crop is not competitive for light, moisture, and nutrients. Although the live mulch system of planted fallow crops is dependent on the availability of appropriate herbicides, the system has a potential in managing

steeplands. Its success depends to a great extent on the choice of appropriate legume cover that can be used as live mulch with a minimal dependence on herbicides.

The amount of N fixed by leguminous cover crops ranges from nothing to about 30 kg/ha of plant-available nitrogen. Psophocarpus palustris, Centrosema pubescens, Mucuna utilis and Crotolaria usually fix from 15 to 30 kg/ha of plant-available N. This low contribution to plant-available N reserve is one of the reasons for the competition for N observed in live mulch system. However, the beneficial effects of mulch cover on soil pysical properties are well pronounced.

29. (v) **Agroforestry:** Agroforestry is a collective name for landuse systems and practices where woody perennials are deliberately used on the land management unit with agricultural crops and/or animals. Trees and shrubs can be periodicaly pruned to prevent shading and to provide additional mulch. Purestand inoculated Leucaena and other quick-growing leguminous shrubs can fix up to 75 to 100 kg/ha/yr of N (Hoegberg and Kvarnastroem, 1982). In addition to fixing nitrogen, deep-rooted perennials also provide a nutrient recycling mechanism that minimize nutrient losses from leaching (Lundgren, 1978; Nair and Khanna, 1975). Deep rooted perennials also improve the infiltration rate and soil structure (Juo and Lal, 1977). An experiment conducted by Hulugalle and Lal (1986) showed that the bulk density of a compacted Alfisol decreased by growing deep-rooted perennial pigeon peas (Cajanus cajan) in rotation with maize in comparison with growing continuous maize (Table 5). Consequently, maize root growth in 20 to 30 cm layer in plots sown to pigeon pea-maize sequence was 82.7 and 67.3% more in zero and reduced-tilled

plots, respectively, than in plots continuously cropped to maize. The grain yield of maize in the pigeon pea-maize sequence outyielded that of the continuous maize sequence by 40.0% and 22.7% in the first and second seasons, respectively.

30. Alley cropping is an agroforestry system in which food crops are grown in alleys formed by hedgerows of trees and shrubs (Kang _et_ _al_., 1985). The hedgerows are cutback at planting and kept pruned during cropping to prevent shading and reduce competition with food crops. An important feature of alley cropping is soil conservation. When planted along the contours of sloping land, hedges decrease both runoff amount and velocity. The data in Table 6 show that _Leucaena_ hedgerows planted two meters apart are especially effective in conserving soil and water. In addition to controlling erosion, alley cropping on Alfisols of about neutral pH (6.0-7.0) can produce satisfactory yield of maize at hedgerow spacing of 4 to 5 m. At closer spacing of 2 m, there is a competition for moisture and shading also reduces maize yield (Table 6). The yield of cowpea may also be suppressed by shading and competition for moisture. Germination of cowpea is suppressed if _Leucaena_ and _Gliricidia_ prunings are incorporated in the top 5 to 10 cm layer 2 to 5 days before seeding. The system, though labor-intensive, can be mechanized to suit the medium-sized farms. Technology for mechanized pruning of hedgerows has yet to be developed.

31. (vi) **Cropping systems:** Extra and quick ground cover provided by compatible mixtures reduces the risk of soil erosion and increases total biomass production per unit area. Crops that provide a slow canopy cover in the initial stages of development can be

profitably grown in association with other crops. Inter-cropping stabilizes yields even at low levels of inputs through better utilization of resources. Disease and pest incidence is much less with inter-crop than monocultures. Consequently, the slow-to-establish cassava is successfully grown in the subhumid zone with maize or cowpea. The cassava and maize intercrop system is widely adapted (Okigbo and Greenland, 1978). Mixed cropping of legumes and cereals is also mutually beneficial. Maize and cowpea intercrop system is adaptable in a wide range of soils and crops. Sole crop maize s gaining popularity in the sub-humid transition zone. In addition, maize can also be grown in association with other cereals (sorghum, millet) and legumes (cowpea, soybean, and phaseolus bean) in semiarid zone.

32. The constraint of high labor requirement for manual land clearing can be alleviated by the introduction of motorized saw. Farmers have to be educated regarding the use of improved tools for hand stumping. The use of no-till farming has been held back by the lack of availability of herbicides to small-land holders. Non-availability of improved seed drills and other hand-powered equipment is another obstacle. Furthermore, farm tools have not been designed for predominantly women farmers of sub-Saharan Africa. Although weeds can be effectively controlled by frequent use of an aggressively growing cover crop, there is a paucity of research information on suitable cover crops and their agronomic management. An acceptable cover crop would be the one that is locally-adapted and that has some additional economic advantages. The same argument

applies, to the choice of tree species and woody perennials to be grown in association with food crop annuals as an agroforestry system. The extra labor input needed for alley cropping and other agroforestry systems can only be justified if the tree species chosen meet other household needs of the rural community e.g. fodder, fuel, fruits etc. Research on species selection and germplasm collection of native species deserve a high priority.

C. SEMI-ARID ZONE

33. The arid-ustic moisture regime of the semiarid regions is characterized with the growing season length of 75 to 149 days. There are a total of about 260 million hectares of land in semi-arid regions of tropical Africa with the growing season length of less than 149 days (Dudal, 1980). These regions are characterized by low rainfall of high annual and seasonal variability and low dependabilty.

34. The most important single climatic factor in semi-arid Africa governing soil productivity is insufficient water supply. Drought stress at critical period of growth is an important factor limiting crop yield. Erosion-induced soil degradation is also of particular concern in semi-arid tropic. Erosion rates of 100 to 1000 t/km^2/year are reported on watershead basis with a delivery ratio of only 10 to 30 percent (Walling, 1984). Over and above these problems, soils are of low inherent fertility. Some technological options are listed below:

35. (i) **Land clearing and development:** The main options of land clearing are hand stumping or mechanized clearing. Similar to other ecological regions, hand stumping is the most desirable.

Although slow and labor-intensive, hand stumping causes the least of problems in soil compaction and accelerated erosion. Of the mechanized clearing, a rear-hitched 9 m anchor chain pulled by two tractors is better than the single tractor technique using the dozerblade (Allan, 1986). All trees are knocked down, and the main root systems and laterals are extracted in the same movement. However, stumping or knockdown is easily done during the rains or when the soil is moist. This means that soil compaction will be severe following the mechanized land clearing. It is advisable, therefore, that the mechanically cleared land is sown to a suitable cover crop for one or two years to improve soil structure, decrease soil erosion risks, supply biomass as mulch material, and to improve soil organic matter content.

36. (ii) **Tillage and soil surface management:** Most Alfisols in semiarid Africa are structurally inert soils. Intensive soil management and tillage studies have been conducted by IRAT in Senegal, Burkina Faso, Niger, Chad and other countries in semiarid Africa. Most experiments indicate the benefits of deep tillage and soil inversion in decreasing losses due to water runoff and erosion (Charreau and Nicou, 1971; Nicou and Chopart, 1979; Chopart, 1981). Nicou (1977) reported a significant increase in available water in the soil profile and of the yield of millet (Pennisetum typhoides) and groundnuts (Arachis hypogaea) from plowing compared with no-tillage systems. Charreau (1977) reported significant increases in yields of pearl millet, sorghum, maize, upland rice, cotton and groundnuts by plowing in comparison with no-tillage (Table 7). The benefits of plowing a structurally inert soil are attributed to an increase in

total and macro-porosity. Experiments conducted in semiarid regions in East Africa have also shown that both primary and secondary tillage are required for improving productivity from compacted soils of low organic matter content (Macartney _et al._, 1971). In some cases, however, the deep tillage can be limited to the row zone only and dead weeds and crop residue mulch can be left on the surface.

37. Ridge cropping, a traditional practice in semiarid Africa, is used on a wide range of soils, crops, rainfall regimes, and topography. Ridge cropping has evolved as an integral component of subsistence farming and is well adapted for small-size, low-input, subsistence farming. Tied-ridging or ridging with the addition of cross ties in the furrows is an improvement over the traditional ridge-furrow systems. This practice is designed to hold surplus water and allow more time for infiltration into soil. In east Africa, tied-ridge system was shown to prevent gully formation (Pereira _et al._, 1958). The beneficial effects of tied-ridge systems depend on soil type. Dagg and Macartney (1968) reported that tie-ridged land produced significantly more grain yield on an Alfisol but not on a Vertisol or an Andisol (Table 8), Similar observations are reported from Zambia by Honisch (1974). The tied-ridge system has also proven beneficial for sandy soils in Burkina Faso. Experiments conducted by IITA (1981) have shown pronounced beneficial effects of tied-ridge system on water conservation and maize grain yield.

38. Self-mulching Vertisols exhibit crumb structure and are easy to manage. At an optimum soil-moisture content, the surface of self-mulching soils exhibits favorable tilth. In such conditions, there is small advantage of plowing or harrowing. In Ghana, Mante

(1979) studied the effects of depth of plowing on physical properties of a Vertisol and sorghum grain yield. No differences in sorghum grain yield were observed for plowing depths of 7.5, 15 and 30 cm depths. For Vertisols with a massive structure, however, effects of plowing on crop yield depend on the rainfall amount and its distribution during the growing season.

39. The use of animal traction in this zone free of trypanosomiasis can raise labor productivity 5 to 10 fold (FAO, 1986). The adoption of animal traction may be easy in semi-arid regions where raising cattle is a cultural tradition. Improved equipment (e.g. no-till seeder, inter-row cultivators, fertilizer applicator, plow, ridger etc.) can be made locally. Draught animal power is often profitable even at low levels of yields in comparison with motorized equipment. It is agued, however, that use of animal traction in field cultivation on a large scale should only be contemplated where permanent cultivation systems currently exist i.e. where land is fallowed a maximum of one year in three (Spencer, 1986). On the other hand, it is likely that the availability of animal traction may lead to the reduction in fallow period and to the introduction of permanent cultivation.

40. (iii) **Cover crops and agroforestry:** In semi-arid regions, growing food crops with an intensive agro-forestry system is faced with the problem of competition for soil moisture even from the deep-rooted perennials. Alley cropping with perennial hedgerows at 4-m spacing is not applicable for regions with erratic and unreliable rainfall. In this situation growing trees and woody perennials on widely spaced contours or on field boundaries is recommended. A

narrowly planted strip of woody perennials can also be planted on widely-spaced contours as shelter belts to reduce the risks of soil erosion, and to use prunings as fodder and the source of mulch. Acacia albida is a useful tree that can be planted on contours. Sorghum, millets and other grain crops can be grown under it without severe yield reduction.

41. Cover crops and planted fallows have definitely beneficial effects on soil physical and nutritional properties (Pereira et al., 1954 Wilskinso, 1975). However, the beneficial effects are transitory and are easily lost during the cropping phase. The choice of an appropriate cover crop and the frequency of its use in the rotation is soil specific and requires local adaptive research

42. (iv) **Fertility maintenance and cropping systems:** In semiarid regions there is a strong interaction between chemical fertility and soil-water availabilty. In regions with unreliable water supply, marginal returns from fertilizer application are lower than in regions with assured water supply. In case of soil moisture deficit, crop response to nitrogeneous fertilizers are lower than to phosphatic fertilizers (Hallsworth, 1981). The application of phosphatic fertilizers may enhance effective utilization of subsoil water through stimulating root growth. Because of the unfavorable water supply, chemical fertilizers should be used as complementary to the biological methods of maintaining soil fertility. Chararreau and Fauck (1970) introduced the concept of basal soil and maintenance fertilization. The basal doze is determined by soil test to correct soil-nutrient deficiencies. The maintenance fertilizer rate depends on crop requirement. Because cattle raising is not limited by

trypanosomiasis, using farm yard manure is a viable alternative to basal dose and maintenance fertilization. Using farm yard manure and compost, therefore, should form an integral component of soil fertility maintenance. Prunings from Acacis albida and other leguminous trees should also be used as mulch. Integrating livestock with tree crops and food crops is an important link to provide the needed diversity for an ecologically sustainable system.

43. Cropping Systems: cereal crops (e.g. millet and sorghum) constitute predominant crops of the region with grain legumes and starchy root tubers as associated crops. Groundnut and cotton are grown as cash crops (Norman et al., 1982). Cereals are mostly grown in mixed cropping patterns in association with groundnuts and cowpeas (Baker, 1974). Andrews (1972, 1974) obtained 59 to 80 percent more returns by relay cropping and intercropping of sorghum with early millet or maize or late planted cowpea. This system of cropping is more productive and profitable and utilizes soil-water and nutrients more efficiently than sole cropping. Mixed cropping involves less risk of failure in a bad year. The sequential cropping recommended for less intensive cropping in Senegal is fallow - groundnut, cereal, groundnut or cowpea. For more intensive cropping, the rotation should be fallow, peral millet, groundnut, peral millet groundnut. In regions where the rainy season is relatively long a common 4-year rotation recommended is fallow, maize (rice or pearl millet), cotton or groundnut, sorghum or pearl millet, and groundnut (Charreau, 1974). Multiple cropping is feasible with proper crop combinations.

44. Return of crop residue to the soil is an important aspect of maintaining soil fertility. In addition to conserving plant

nutrients, crop residue returned to the soil conserves soil and water and improves soil physical and biological properties (Kowal and Kassam, 1978; Chaminade, 1972). The challenge lies in introducing crop rotations and cropping systems that will produce enough biomass for alternate uses. Although mixed cropping is a viable alternative to sole cropping, research is needed in developing appropriate agronomic practices e.g. improved varieties adapted to intercropping, weed control, time of planting associated crops, and on possibilities of mechanizing such systems. The rotation systems developed must also involve the use of planted fallows to restore soil fertility. Effective use of the tied-ridge system also depends on developing animal-driven equipment to reduce human drudgery in making ridges.

45. Early seeding and establishing an optimum crop stand are the critical aspects of improved cropping systems. The time of planting a crop should be such so as to match the expected rainfall patterns with the most critical stage of crop growth. Premature sowing in case of erratic early rains cause poor germination and a patchy stand. Delayed sowing in case of heavy and frequent early rains is often responsible for drought stress late in the season when rains end abruptly. Reliable methods of medium-range weather forecasts for period of 5 to 10 days ahead are essential for predicting the onset of rains. In addition to planting early in the season, soil moisture storage and the yield of the following crop can be drastically improved by partial or complete fallowing for one or two seasons. For fallowing to be successful, however, an effective weed control during the fallowing is essential.

D. ARID ZONE

46. Arid regions have a growing season length of less than 75 days. The mean annual rainfall ranging between 400 and 750 mm is highly variable in time and space. Rainfall is received as high intensity thunderstorms concentrated in 40 to 60 days. Both water and wind erosion are, therefore, severe constraints. A major cause of erosion and erosion-induced soil degradation is the high population of cattle and small ruminants and uncontrolled grazing. The animal populaton is particularly high around reliable sources of water. The characteristic feature of this zone is nomadic pastoralism.

47. Water management, soil conservation, and soil fertility maintenance are the crucial issues. One of the limitations to providing effective guidelines for improving productivity of traditional farming systems in this region is paucity of basic research data on resource management for sustained productivity. Few long term experiments have been conducted to provide the much-needed information on sustainable systems of soil and crop management. Some general views on technological options are described below:

48. (i) **Soil and water conservation:** Harmattan, the dry north-easterly wind that occurs from November through February, causes considerable wind erosion. Day time air temperatures during Harmattan often peak about 38°C and fall to 10 15°C during the nightime. The ultra-desiccation of soil during this period of low relative humidity (less than 25%) has adverse effect on soil structure. Wind erosion is controlled through shelterbelts created by planting appropriate tree species as hedges. While establishing the shelterbelts, sand stabilization and dune fixation should also be done simultaneously.

49. Because the rainfall is concentrated in 2 to 3 months, flash floods from overgrazed and denuded lands cause severe sheet and gully erosion. Some of the promising cultural practices to increase infiltration and decrease surface runoff are contour planting, growing vegetation or grass strips to reduce runoff velocity, installation of infiltration ditches, and construction of earthen small check dams. Establishing any type of vegetation cover is a useful measure in soil and water conservation.

50. In addition to decreasing runoff and controlling erosion, effective utiliztion of soil-water stored in the root zone is the key to good crop growth and satisfactory yield. Water mangement techniques involving micro-catchments, water spreading and water harvesting, and water storage in small-size farm ponds for life-saving supplementary irrigation are important considerations. Development of farm pond and small-scale irrigation schemes should be preferred over the grandiose and capital-intensive large-scale irrigation projcts. However, no data is available validating the application or adaptation of these techniques for diverse soils and crops of this ecological region.

51. (ii) **Landuse:** Determining landuse capabilities, using land for whatever it is suitable for and adopting farming systems that will realise its potential are important steps towards the long range planning for effective development and utilization of these resources. The landuse should be preferably planned on watershed basis and should involve integration of agriculture, forestry and animal husbandry. Small watersheds should be developed for the diversified and multipurpose landuse e.g. farm pond for storage of surplus runoff,

forestry plots for fuel wood, fodder bank for controlled grazing, and arable landuse for food crop producton. Land tenure systems and local customs may present obstacles to the implemention of planned watershed programs. However, adaptation may be easier once the rural community is shown the benefits and convinced of this approach.

52. (iii) **Agroforestry and cropping systems:** In traditional systems, trees, shrubs annual crops and animals are integrated in an extensive farming system. Food grains such as sorghum, millet, maize and cowpea are grown inbetween the standing native Acacia sp. Vast areas are used for extensive grazing. To begin with, these traditional landuse systems should be systematized for an intensive landuse. Some suitable tree species for intensive agroforestry and soil fertility maintenance are Acacia albida, Acacia senegal, Parkia clappertoniana, Tamarindus indica, Butyrospermum paradoxum, Borassus aethiopum and Hyphaene thebaica (NRC, 1984). Some of these trees are multipurpose. Acacia albida is a leguminous nitrogen-fixing tree and is important for soil fertility maintenance. Because of the reverse foliation, it sheds its leaves during the rainy season, and does not compete with crops for light. The leaf litter is the source of the nutrient-rich mulch. About 20 adult trees of Acacia albida per hectare is the optimum tree density. These trees can be planted at random, on the contours as shelterbelts, in strips as fodder-cum-fuel banks, or in contiguous areas specifically demarcated in the watershed for afforestation. The associated crops may be food grain or fodder species as the case may be. The commonly recommended rotation cycle for food crops involve maize-cotton, sorghum plus cowpea, groundnuts and grazed fallow (FAO, 1981). In addition to the fertility-

restoration trees, some fruit and shade trees can also be grown in association with food crops. Appropriate fruit trees include Mangoes, Zizyphus sp. and Ficus spp. Acacia senegal is useful for the harvest of its gum.

53. Supplemental irrigation to overcome increasingly erratic water supply is bound to reduce the vulnerability of crops to drought stress in arid regions. However, development of large-scale irrigation scheme is capital-intensive and can be counter productive. Small-scale, labor-saving irrigation schemes based on farm ponds or water lifting devices using animal power are more appropriate for the African situation. The potential for developing, low-cost, small-scale irrigation schemes in West Africa awaits development and merit a high priority.

CONCLUSIONS

54. Inspite of the discouraging trends of perpetual food deficit in Africa, it is apparent that the soil and water resources of Africa have a potential to produce enough to meet the need for food and other requirements of the present population. In fact, recent estimates by Higgins and Kassam (1984) have shown that, if used properly, soils of tropical Africa could at low levels of inputs produce food sufficient for thrice the 1975 population and for one and a half times the projected populaton of Africa in the year 2000. At intermediate levels of inputs, Africa could feed five times the population projected for the year 2000.

55. The Green Revoluton of the mid-1960s in Asia occurred due to the use of improved varieties and often with irrigation on fertile lands. In comparison, a majority of African soils are marginal uplands. Improving yield on marginal uplands requires appropriate resource management strategies. Some useful and yield-increasing technologies are available and are now awaiting validation in different agro-ecological regions and eventual transfer. Soil and water management techniques are known for better soil and water management and erosion control with appropriate tillage and soil surface management. Soil fertilty can be improved through growing planted fallows, adopting agroforestry measures, and integrating livestock with food crop producton. Research and development priorities should be given to small-scale irrigation and to development of soil and water management techniques that involve the maximum utilization of rainwater for crop use.

56. Although technologies have been developed, they are yet to be tested and validated for different soils and agroecological regions. These technologies have to be adapted for the specific socio-economic needs of the region (Table 9). Site-specific adaptive research can be made cost-effective by organizing research into coherent networks. Researchers from the national research institutions should take active part in these networks whereby properly organized experiments are conducted with uniform methodologies so that results are comparable.

57. Managements of soil and water resources is the key to intensifying agriculture and improving food production in tropical Africa. The challenge of food and agricultural improvement in

tropical Africa can be met by enabling the traditional resource-poor peasant farmer to produce a surplus. Improvements can be brought about on the basis of resource-efficient technologies with adequate incentives through judicious pricing policies, and by providing storage and marketing facilities. Food self-sufficiency can be achieved by using the technical know-how available, by making domestic capital available for investment in agriculture, and by the determination and resolve of the people and governments concerned.

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Table 1. Effects of tillage methods and mulching on tuber yield of yam and cassava at Onne, near Port Harcourt in the humid coastal lowland region (Opara-Nadi and Lal, 1986).

Treatment	Yam	Cassava
No-till, without mulch	9.8	12.7
No-till, with mulch	11.9	16.8
Plowing, without mulch	10.9	13.1
Plowing, with mulch	13.9	14.5
LSD(.05)	2.1	

Table 2. Effects of methods of land clearing on water runoff and soil erosion over a 3 year period from 1979-81 from an Alfisol at Ibadan in Subhumid tropical upland zone (Lal, 1981b).

Treatment	Runoff (mm)	Soil erosion (t/ha)
Forest	1	0.01
Traditional farming	6.6	0.02
Manual clearing	47.9	2.6
Shear blade clearing	104.8	4.1
Treepusher - root rake clearing	250.3	20.0

Table 3. Effects of clearing methods and Mucuna cover on total porosity and infiltration rate of an Alfisol at Ibadan in subhumid tropical upland zone (Hulugalle et al., 1986).

			Infiltration	
Clearing method	Cropping system	Total porosity (%)	mm/h	Cumulative mm/3 h
Manual	Maize-cowpea	0.55 b	0.02 cd	608 bc
Manual	Mucuna	0.59 a	0.08 a	1422 a
Shearblade	Maize-cowpea	0.54 c	0.02 cd	492 cd
Shear blade	Mucuna	0.57 b	0.04 b	764 b
Tree pusher	Maize-cowpea	0.57 b	0.02 cd	287 de
Treepusher	Mucuna	0.59 a	0.004 d	329 de
Treepusher-rootrake	Maize-cowpea	0.53 c	0.002 d	193 e
Treepusher-rootrake	Mucuna	0.53 b	0.03 bd	557 bcd

Values within the same column followed by the same letter do not differ significantly at the 5% level of probability.

Table 4. Mulch prouncement technologies.

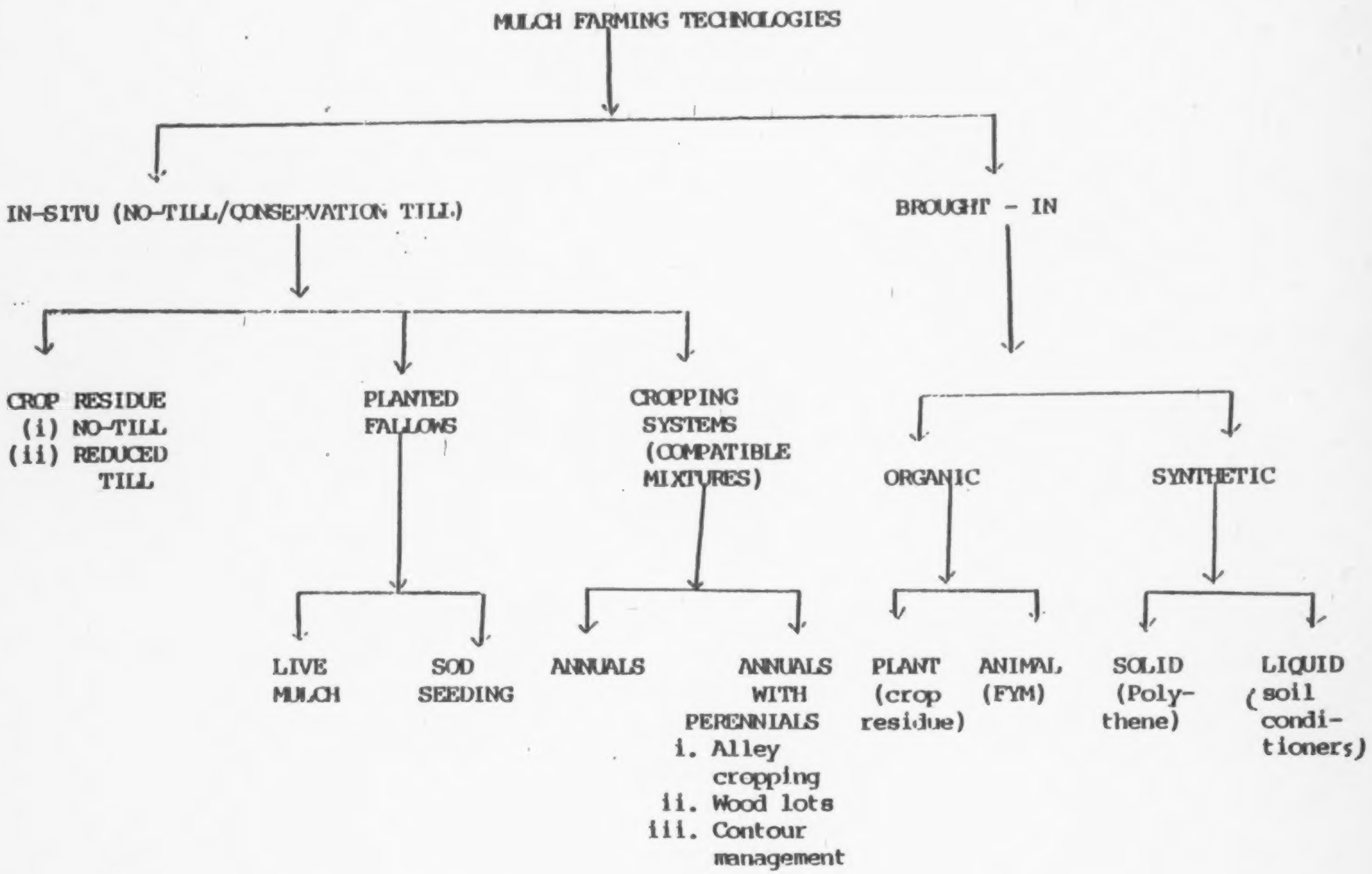

Table 7. Mean effect of plowing on yields of crops in the West African dry tropical area (IRAT Experiments: Soil surface layers, sandy to coarse loamy), 1952-1969 (Charreau, 1977).

Crops	Vegetation removed before plowing			Vegetation incorporated by plowing		
	Yield on unplowed controls (kg/ha)	Increases from plowing		Yield on unplowed control (Kg/ha)	Increases from plowing	
		kg/ha	%		kg	%
Pearl millet (grain)	1,245	+256	+21	971	+365	+28
Sorghum (grain)	1,874	+536	+29	2039	+532	+26
Maize (grain)	2,093	+568	+27	1474	+970	+66
Rainfed rice (paddy)	966	+1515	+157	1547	+705	+46
Cotton (seed)	1,629	+433	+27	1240	+423	+34
Groundnut (pods)	1,412	+274	+19	1661	+119	+7

Table 8. Maize grain yield from a mechanized tie-ridge system for three soils in Tanzania (Dagg and Macartney, 1968).

Soil	Maize grain yield (kg/ha)		
	Tie-ridged	Ridge	Flat
Vertisol	3274	3251	3085
Alfisol	3433	3029	2628
Sudisol	1763	1113	1815

Table 9. Constraints towards adoption of improved technologies and the need for action.

Constraints to adoption	What should be done
A. Manual land clearing	
1. High labor requirements.	1. Adopt legislation to prohibit the use of bulldozer and other heavy equipment.
2. Women farmers are unable to use chain-saw.	2. Provide credit for purchase of improved tools e.g. chain saw.
3. Slow and tedius.	
4. Adopt cultural practices that enhance production from existing lands.	
B. Conservation Tillage	
1. Non-availability of herbicides and spraying equipment	1. Research is needed to develop alternative methods of weed control e.g. covercrops, crop rotation, etc.
2. Lack of seed drills and appropriate farm equipment.	2. Local industry should be encouraged to manufacture manually-operated or cattle-driven improved farm equipment. Improved equipment is required especially for use by women farmers.
3. Lack of mulch material and the need of crop residue for other uses e.g. fodder food etc.	3. Improved cropping systems should be researched that provide mulch material for alternative uses.
4. Women farmers are not used to the special requirements of no-till farming.	4. Alternative sources of household fuel should be developed.
5. High risks of pest build-up when mulch is left on the soil surface.	5. A co-ordinated network on soil management research is needed for different ecological regions.
6. Lack of knowledge on Soil-guide to tillage requirements for tropical crops.	6. Research need for developing tillage implements for animal traction.
7. High energy input for constructing tied ridges.	
C. Agroforestry	
1. High labor demand for pruning and hedgerow maintenance.	1. There is a need to develop improved hand and motorized tools for shrub pruning and

Table 9. (Contd.)

2. Lack of knowledge for appropriate species of trees and woody perennials.	hedgerow maintenance. 2. Research is needed on species selection and on crop management for crops grown in association with trees and woody perennials.
3. Lack of knowledge on management practices for appropriate agroforestry systems and on tree-crop campatibility.	
D. Cropping systems and weather	
1. Lack of reliable method of weather forecasting to enable decision on correct time of planting.	1. Research is needed on weather patterns and forecasting and on predicting effective soil-water reserves.
2. Appropriate (mixtures or relay crops) that ensure a minimum yield in bad years.	2. Longterm agronomic research is required on crop rotations, mixed cropping and relay crpping for different soils and agro-ecological regions.

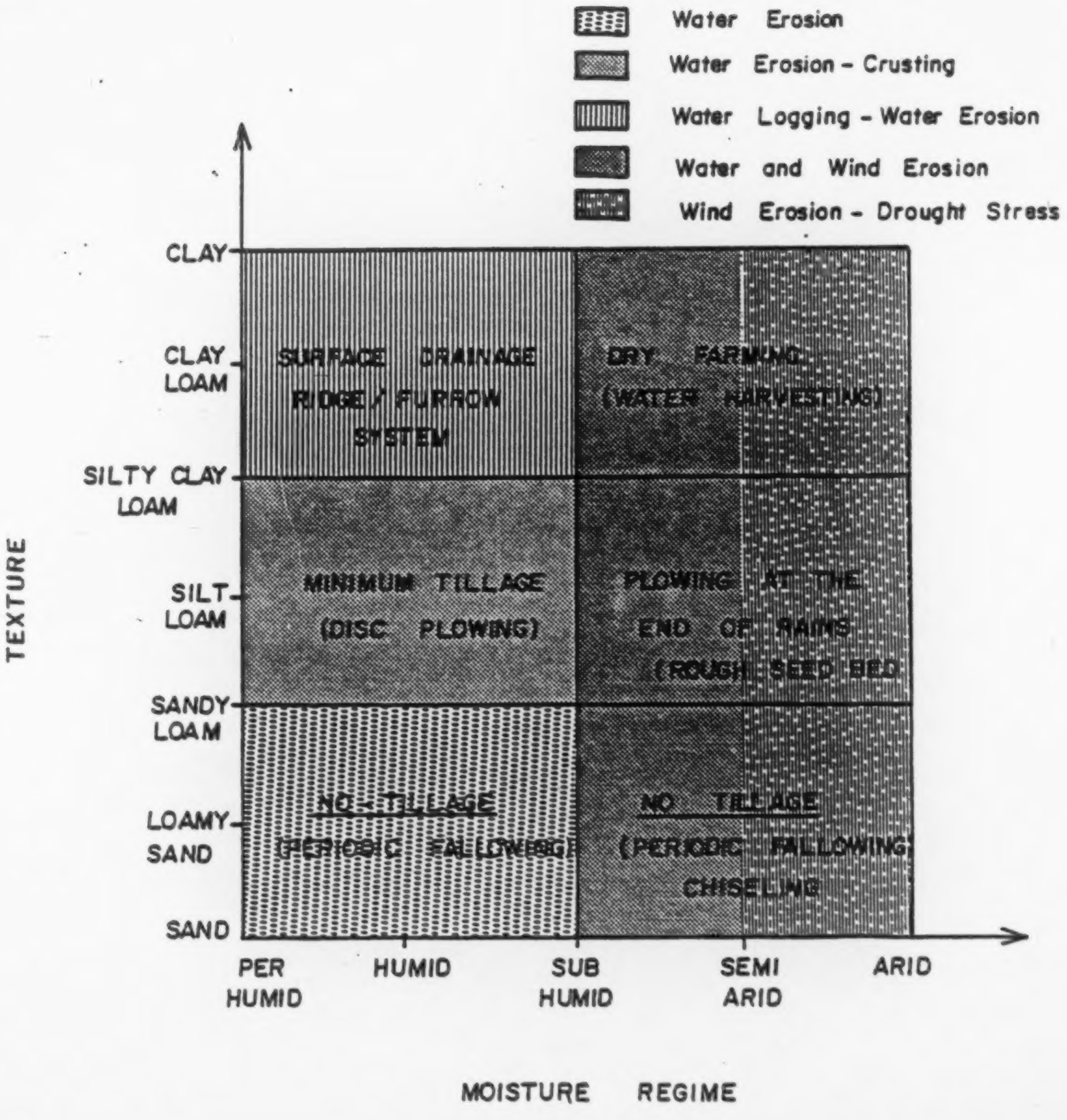
Water Erosion
Water Erosion - Crusting
Water Logging - Water Erosion
Water and Wind Erosion
Wind Erosion - Drought Stress
CLAY
CLAY LOAM
SILTY CLAY LOAM
SILT LOAM
SANDY LOAM
LOAMY SAND
SAND
TEXTURE
SURFACE DRAINAGE RIDGE / FURROW SYSTEM
DRY FARMING (WATER HARVESTING)
MINIMUM TILLAGE (DISC PLOWING)
PLOWING AT THE END OF RAINS (ROUGH SEED BED)
NO - TILLAGE (PERIODIC FALLOWING)
NO TILLAGE (PERIODIC FALLOWING) CHISELING
PER HUMID
HUMID
SUB HUMID
SEMI ARID
ARID
MOISTURE REGIME

Fig. 1. Soil guide to appropriate tillage systems in tropical Africa (Lal, 1985).

FINAL DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

Five Small Scale Water Management Technologies

by

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FINAL DRAFT

Five Small Scale Water Management Technologies

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Five Small Scale Water Management Technologies

I. Abstract

Summary

Water management means processes to increase the utility of water for the benefit of people, crops, and animals. Simple water management technologies suitable for low-resource agriculturalists in Africa include water harvesting micro catchments, tied ridges, contour planting, terracing, and recession farming.

These water management technologies are being practiced in various African locations, but they have received inadequate attention in the past from local scientists/engineers and technical assistance personnel. Good farmers have adopted them, but many others have not. Development assistance organizations have not implemented projects focused on small scale water management technologies, but there are a few exceptions.

There are specific requirements for site characteristics, construction activities, and crop selection for each of the technologies. Rainfall and soils are the most critical.

Because of the important role they play in food production in Africa, women will be affected by introduction of new/improved water management technologies. They will probably see changes in their work load but may also receive greater benefits from the new systems.

A number of policy issues are raised by the concept of implementing programs of small scale water management. Of major importance are the long-term nature of the problems and their

solutions, the need for many trained professionals, and the requirements for pilot projects and adaptive research in Africa.

There are many areas in Africa where these technologies are potentially useable, however details are lacking on specific applications. A preliminary feasibility study will be an important first step.

Most important message

Good water management is critical for increased food production by low-resource agriculturalists in Africa, especially in the arid and semi-arid regions but also in more humid zones. The potential for application and/or improvement of small scale water management systems is high although greater attention and effort by the scientific/engineering community, host country governments, and donor agencies will be required to attain widespread implementation.

II. Description of water management technology

1. Water management is the term applied to processes aimed at increasing the utility of water for the benefit of people, their crops, and their animals. Many of the processes also are referred to as soil and water conservation activities because they accomplish both purposes (Schwab, et al, 1981).

2. There is a spectrum of water management, extending all the way from simple technologies to complex systems of irrigation and drainage with every drop and every movement of water as carefully controlled as possible. The major thrust of water management work around the world has been on large-scale, capital-intensive, state-managed irrigation and drainage systems in which the goal is complete management of all water in time and space (Jensen, 1981).

3. The focus of this paper is on five simple water management technologies: water harvesting micro catchments, tied ridges, contour planting, terracing, and recession farming. Several other small scale water management technologies of a similar nature are equally suitable for adaptation/improvement in Sub-Saharan Africa. Among them are the following:

- technologies in rainfed farming
    - adjusting plant population to available water
    - mulching
    - selecting optimum planting date
    - soil moisture traps or barriers
    - alley cropping/agroforestry
    - fallow systems

- water conservation technologies
  - evaporation control
  - seepage reduction
- water resources development technologies
  - fog catchers
  - pumping from rivers
  - diversion of river/stream flow
  - water spreading
  - springs and horizontal wells
  - pumping from shallow wells
  - subsurface dams
  - salt water intrusion barriers
- technologies of small scale irrigation and drainage
- related technologies
  - hand and animal-powered pumps
  - micro hydropower development
  - water storage in reservoirs, tanks and cisterns
  - erosion control structures
  - range pitting or imprinting
  - aquaculture ponds
  - domestic water supply systems
  - waste water treatment and reuse.

Water harvesting micro catchments

4. Water harvesting refers to a system of production in which a portion of the total area available to a farm family is used as a catchment to produce as much runoff as possible. Another portion of the area is used for cultivation of crops and receives runoff

from the catchment in addition to direct rainfall (Shanan and Tadmor, 1979; Dutt, et al, eds., 1981). Micro catchment water harvesting includes modified furrows in which row spacing is doubled with the space inbetween rows sloped toward the plants. Excess runoff may be caught in a reservoir and used for supplemental irrigation of the crops in the cultivated area during rainless periods or may be conveyed to a nearby watercourse. Successful crop production with water harvesting depends on having a soil, either existing or artificially created, which is deep and has high available water-holding capacity (AWC) (Matlock and Dutt, 1986). The ratio of catchment area to cultivated area is a function of climate, crop water requirements, soil AWC, and reservoir capacity, if one is used. A reservoir reduces the importance of having a soil with high AWC. Water harvesting principles also are used to provide water for people and animals (Frasier and Myers, 1984; Pacey, 1986).

Tied ridges

5. For this system, the furrows between closely-spaced soil ridges are divided into closed micro basins 1 to 5 m long by cross-ties (small dams), and runoff is prevented. The use of tied ridges provides a way of capturing and holding rainfall near where it falls in a cultivated area and allowing it to infiltrate there. Soil water storage is increased because of lengthened infiltration opportunity time. The ridges are constructed along contours and the cross-ties are kept lower than the ridges so that they act as spillways in the event of excess rainfall. Tied ridges have been

most successful on deep soils (Hudson, 1971), but deep, high permeability soils are not necessary.

Contour planting

6. In this system of production, crops are planted in rows which follow the elevation contours of the land surface. Furrows and/or ridges (dikes or bunds) constructed of local soil and/or rock materials may or may not be used, depending on slope. Traffic of tillage operations whether by hand or mechanized is concentrated along the rows, not across them. Runoff across the slope is slowed or stopped, and infiltration is enhanced (Hudson, 1971). When dikes or high ridges are used, the areas above and immediately below the dike receive an increased supply of soil moisture, and many different crops are planted in those locations.

7. The method can be used on mild or steep slopes, but in the latter case, careful attention must be given to the problem of overtopping the contour dikes during major storms and subsequent washout of the entire system or hillside. Cross-dikes can be used to confine the washout, or spillways can be included at regular intervals to carry the excess flow.

Terracing

8. Terracing is an ancient technology, practiced in many locations. A contour dike is thrown up at the downstream side of the terrace. Soil within the terrace is left in the natural condition (on mild slopes only), graded to a mild slope, or levelled. Terrace ends may be closed or open to a waterway for safe removal of excess flow. Terrace systems are used for a wide variety of crops including trees of different types.

Recession farming

9. Annual floods of major rivers in areas of low topographic relief result in inundation of vast areas of land along the river. The water saturates the floodplain soil to depths dependent on the duration of the flood and soil characteristics. A similar situation exists around lakes and ponds or small reservoirs which are influenced by an annual flood.

10. As the flood recedes, farmers make shallow holes up to one meter apart, usually with a planting stick. This is done as soon as the surface water is gone but while the soil is still very nearly saturated. Sand may be put in the holes to avoid crusting problems, and seeds are planted in the sand. The plants utilize the water which was stored in the soil during the flooding period. The amount of water available for plant growth is determined by the physical and chemical properties of the soil.

11. Sometimes the growing season is lengthened by early planting in high areas at the peak of the flood. Established plants then are transplanted from the higher locations where moisture has already been used to newly exposed, lower soils.

12. The flood recession system works well for crops which have a short growing season such as sorghum and millet. Only the heavier soils in the lowest depressions are suitable for this type of farming because they are flooded long enough to absorb sufficient water and have the proper physical conditions to retain it. A controlled, artificial flood is being planned for the Senegal River as a means of continuing use of this method of production even as new irrigation systems are being developed.

Benefits of water management

13. There are technical, social, institutional and economic benefits of water management technology, in general, if used properly, and specifically of the five technologies discussed above. Technical benefits include reduction or avoidance of soil salinity and alkalinity problems, reduced soil erosion, maintenance of soil fertility and productivity, and effective soil-water storage. Other technical benefits include enhanced infiltration, increased use of available water resources, flood control, ground water recharge, and reduced sedimentation of reservoirs. Improved water management in one location on the watershed may result in increased problems downstream because of changes in the hydrologic regime, especially in the short term. Better overall management of a watershed can be beneficial to all concerned in the long term, but the current water needs of downstream users must be considered.

14. Social benefits include increased opportunity for employment in project development, more water available to the low-resource agriculturalists, reverse migration of people from the urban areas, lower food prices, and improved health.

15. Institutional benefits of involvement in water management programs include gaining increased knowledge of existing agricultural systems, development of a cadre with expertise adapted to the local physical and social environment, more satisfaction from working on and solving problems of low-resource agriculturalists (a target talked about but seldom reached), and greater recognition by local governments of the ability of the institutions to resolve local problems.

16. Economic benefits of water management include increased production of various crops. A small amount of water at the right time can make the difference between successful crop production and crop failure. Water management makes this possible. In an Arizona experiment, water harvesting supplies 87 percent of the total water requirements for perennial fruit crops from direct rainfall and runoff from the catchment in an average rainfall year (350 mm). But the remaining 13 percent of requirements, supplied from a reservoir which stores excess runoff from the water harvesting system, is critical in making crops productive rather than merely surviving. (Matlock and Dutt, 1986).

17. These technologies permit extension of the zone where a particular crop can be grown or changing to a crop which has a greater water use requirement (and usually higher unit value of production). The growing season also can be extended.

18. The actual increase in production which can be obtained from any of these water management technologies cannot be stated conclusively without specifiying the time and the place. In a year with very low rainfall, none of them will insure a harvest (unless a storage reservoir is part of the system). In a year of very high rainfall, they probably will not yield much more than the do-nothing case. But for years in between those two extremes, the water management technologies will result in greater stored soil moisture and consequently greater crop production. Pacey (1986) points out that for a runoff farming scheme in Burkina Faso the yield was little more than that obtained from traditional farming methods in 1982 when rainfall was about 450 mm. But in 1983,

described as a drought year, the yield from the runoff farming area was 48 percent greater. Probability analyses of rainfall are necessary to quantify potential benefits in a given location.

19. Incidently, if year-round water storage is made part of their systems, the low-resource agriculturalists may have the option of engaging in aquaculture (fish farming).

III. Status of water management

Status in general

20. Water management has not been given adequate consideration and/or emphasized sufficiently by planners of agricultural development, especially for projects in those arid/semi-arid regions where there is no possibility for large-scale, capital-intensive, state-managed irrigation. Engineering expertise usually has not been applied in project design, and agricultural engineers or irrigation engineers are seldom on project teams. Yet water is the primary limiting factor for crop production in the arid/semi-arid lands.

21. Small scale water management systems are given even less attention. Scientists/engineers in both developing and developed countries (including the U.S.) have limited experience with water management on a small scale. They often tend to ignore these technologies or look down upon them as undeserving of their attention.

Geographic scope of adoption

22. The five small scale water management technologies discussed above (and others) are found in appropriate locations throughout Africa. Water harvesting micro catchments have been

introduced in Cape Verde, Burkina Faso, and Kenya (Pacey, 1986). Tied ridges are found in Malawi, Niger, and Botswana (Evett, 1986). Contour planting and terracing have been used for a long time in all the African countries. Recession farming is found along the major rivers of West Africa--the Senegal, the Volta, and the Niger--as well as on the margins of temporary ponds and lakes which line the tributaries. The Nile Valley in Egypt is an example of the evolution of irrigated agriculture from recession farming. Thus, these technologies do not represent new discoveries. Nevertheless, other than recession farming, which seems to be practiced wherever possible, their use is not widespread even in the areas where they currently are found.

Farm level adoption

23. Good farmers understand very well the principles of water management and use them effectively in managing water available to them for crop production. They use technologies which are appropriate for their location and scale of operation. Other farmers may understand the importance of water but do not practice good water management to the same extent.

Adopting farmers

24. The effective users of innovative water management technologies tend to be those with more access to land and water resources. The better farmers in more favorable locations adopt suitable new technologies as they become aware of them. But other farmers do not need to have very large areas for effective use of these technologies. In fact, concentration of scarce water resources developed through small scale water management systems on

small areas may have some advantages. For example, preliminary calculations made for Cape Verde show that an intensive garden of only 500 m^2 with adequate water for two crop seasons per year will provide all food requirements for a family of six. Developing and storing the water to accomplish this is a reachable goal.

25. A single tree can make a difference. The value of the production from a mature, well-cared-for fig tree in Jordan is as much as $300 per year (Qashu, 1984). Thus, permanent access to very small units of land combined with improved water management could increase annual income substantially for low-resource agriculturalists.

26. Most farmers who have not managed water in the past have difficulty in managing it effectively when a new system is made available to them unless they specifically are trained to do so.

Status with major development agencies

27. Major development agencies have given little attention to water management in general and to small scale water management systems in particular. The USAID Water Management Synthesis II (WMSII) project is an attempt to bridge this gap, but it operates for the most part as an appendage to existing projects with considerable negotiation required for WMSII personnel to become involved in other on-going or planned projects. The focus of WMSII has been on large-scale, capital-intensive, state-managed irrigation and drainage projects although some attention has been given to small scale irrigation (Coward, 1984). Recent WMSII project activities in Mauritania have indicated some potential for water harvesting there.

28. The USAID watershed development project in Cape Verde stands out as an exception. Small scale water management systems are being introduced to low-resource agriculturalists. Combination of PL-480 grain revenues in a program of employing rural people for constructing water control structures has accomplished much in the last few years.

29. UNESCO has been conducting a major regional project on the rational utilization and conservation of water resources of rural areas of Africa (south of the Sahara) for several years. Its focus has been more on village water supply than on water for crop production, but project administrators indicated a willingness to cooperate on a water harvesting pilot project in Mali by paying local costs. Unfortunately the proposed project was not funded.

30. The World Bank has been involved with improvement of hand pumps in a world-wide project. Some field evaluation work has been done in Africa.

31. Several of the PVO's have added water management activities including the technologies discussed in this paper to their village-level projects in African countries (Pacey, 1986).

32. The U.S. Peace Corps has carried out small water resources development and management projects in a number of African countries. Notable for its successes since the early 1980's is the Peace Corps program in Burkina Faso (Evett, 1986).

Costs

33. Data are lacking on costs of small scale water management systems. They are not low-cost if construction is done in a capital-intensive manner, but most construction can be done with

farmer-supplied labor working in the off season. However, cost of using hand labor for such tasks has not been carefully documented, nor has cost of use of local materials--earth, rocks, wood--which often are entirely suitable for the necessary construction. Some supplies, equipment, and tools are required. In addition, there are costs associated with operating and maintaining the new systems with their level of management higher than traditional systems.

33A. The costs of the five small scale water management technologies highlighted in this paper also are site-specific. Operations which may be involved include land clearing (removal of vegetation and rocks); land preparation (smoothing, shaping, compacting, and tilling); planting, cultivating, fertilizing, and harvesting (these may be similar to existing practices, but probably will be more intensive); managing and controlling water; and maintenance (preventative and repair of damage). Required materials, supplies, and equipment may include soil, clay, sand, gravel, rocks, cement, wire, fencing, concrete blocks, shovels, hoes, picks, rakes, scrapers, and tampers. Estimating costs of a proposed project will require knowledge of local labor costs and time required using local labor to accomplish the listed operations. Costs of the materials, supplies and equipment in that location must be known. Pilot projects will be useful in estimating costs of full scale implementation.

Negative impacts

34. There may be increased competition with herders for lands previously used only for grazing. Catchments for water harvesting often are cleared of all vegetation and thus become unavailable for

grazing. Earthwork may be damaged by the passage of animals grazing on crop stubble. Marginal lands may be brought into more intensive use, requiring greater concern for potential degradation, especially during drought years (Dregne, 1983).

35. The concentration of water behind dikes or ridges creates great hazards of flooding and subsequent washout of the system in the event of unusually high and/or intense rainfall. Spillways and controlled waterways will be needed to convey the excess water away without damage to the production system. Good design is critical; engineers and hydrologists must be consulted.

36. These systems of production do not represent a miracle or "breakthrough" technology. Any crop production system entirely dependent on the vagaries of rainfall will experience crop failure or reduced yields from time to time.

Key constraints

37. There is a notable lack of experience in water management among technical assistance personnel. This gap is equally evident in local and expatriate personnel.

38. The economic advantage of these systems of production is modest, not spectacular. Unit production costs may be higher than those from well-managed, large-scale, capital-intensive irrigation, where that is possible.

39. Local adaptation of the technologies is required before they can be used extensively in a new area. This takes time.

40. There is some difficulty in working simultaneously with large numbers of individual farmers in scattered locations, because

their problems and conditions are not the same. Program planning and implementation must be carefully orchestrated.

41. Good attention to engineering detail, particularly in land surveying and layout, is critical. Regular maintenance of the small scale water management systems by the low-resource agriculturalists is essential.

IV. Requirements for implementing water management technologies

42. Characteristics of the five technologies and requirements for their implementation are summarized in Table 1.

Information on climate

42A. These water management technologies are dependent on making use of available rainfall and on controlling runoff. Detailed climatic analysis for the proposed area is necessary; the analysis should include studies of seasonal rainfall probability. Analyses of rainfall intensity and individual events are more important than average annual rainfall for some technologies. Such studies are better if based on detailed, preferably daily rainfall records which likely are unavailable for many potential sites in Sub-Saharan Africa. Experienced climatologists can use the limited data available, supplemented by more detailed data from nearby locations.

Site characteristics

43. Examination of Table 1 shows that each of the technologies has specific requirements for suitable environments for its use. A minimum level of average annual rainfall is essential for their success. There also is a maximum level of average annual rainfall above which their use probably is not profitable. At the same time

there must be provision for dealing with excess rainfall or runoff. A higher level of specificity of criteria is desirable for design purposes; more field data are necessary to accomplish that purpose.

44. All of these technologies depend on increasing the storage of water in the soil zone. For that reason a deep soil, with high available water-holding capacity (AWC) is desirable. For the very small systems, farmers may modify the soil extensively with manure and other organic materials or by mixing with other soil to achieve the desired physical characteristics.

Construction activities

45. The construction tasks required for these technologies may include earth excavating, placing, shaping, grading or levelling, and compacting. Structures to be built include catchments, dikes or berms, canals and waterways, spillways, and reservoirs. In addition to earth materials, rocks, concrete, soil cement, and ferrocement will be used. Plastic or metal pipe and sheets may be used. Cultivated areas will be graded or levelled. Soil in the cultivated area may be excavated, mixed and replaced.

46. All of these technologies can make use of local resources for construction, operation, and maintenance. Hand labor can be used although mechanization may be desirable to avoid undue delays. Animal traction is another option. For example, ox-drawn "furrow-dikers" can be used in making tied ridges. Local earth (soil) and rock materials can be used for construction of water control structures. In some cases local wood materials may be suitable for construction.

Table 1. Summary of characteristics and requirements of some water management technologies*

Technology	Rainfall zone	Topography and soils	Construction tasks and methods	Water storage
Water harvesting micro catchments	0.3-0.8 RF/PET ratio, minimum 300 mm	deep soil, high AWC, mild slope, catchment can be steep	earth moving and shaping, hand labor or mechanized	soil zone, may have reservoir
Tied ridges	minimum 400 mm*	deep soil, high permeability, mild slope	construct ridges and cross-ties, hand labor or mechanized, special implement available	soil zone
Contour planting	minimum 400 mm*	mild to moderately steep slope	layout fields, construct dikes, hand labor or mechanized	soil zone near contour dike
Terraces	minimum 400 mm*	mild to steep slope, deep soils if graded or leveled	construct dikes, grade or level soil, hand labor or mechanized	soil zone
Recession farming	n.a. (any area flooded for long periods)	low, flat areas, deep, heavy soils	hand labor, mostly temporary water control structures	soil zone

RF/PET--rainfall/potential evapotranspiration
AWC--available waterholding capacity
* Information presented is intended to provide guidelines for these technologies, not absolute limits

47. Women and children can be involved in the construction, operation, and maintenance of small scale water management systems. The systems often can be located near the villages or even in a residence compound. They provide an opportunity for intensive production, e.g., intensive gardening, on small plots.

48. Farm families can do the work of constructing new and/or improved water management systems if they are given assistance by the government and donor agencies. Some capital assistance may be required for implementation, particularly for region-wide programs, but little additional input is required from the government after the system is in operation other than providing new information on the technologies related to their use in that region or country as it becomes available. There is no need for any cumbersome, expensive government bureaucracy. Pilot projects will be useful in adapting the technologies to local conditions and as extension centers for training technical assistance personnel and farm families.

Crop selection

49. Because of the investment of labor and materials in these water management technologies, and because the end result is to provide additional water, farmers will be interested in growing higher value crops than have been traditionally grown in their area. Vegetables, fruit and nut vine or tree crops, and other specialty crops likely will be considered, depending on marketing conditions and storability of the products.

Other production practices

49A. Improved water management will go for naught without improvements in other production practices. Especially important are fertility management and maintenance of organic matter levels in the soil. Pest control problems likely will increase with a more humid environment. Improved agronomic practices are essential, and sustainability of resources is paramount.

V. Impact of water management technologies on women

50. African women have a major role in food production. For this reason, any change in the system will affect them.

Work load

51. The work load of women may be increased during the construction of new water management systems. This may be paid or unpaid labor. Women likely will have increased responsibilities in operation, maintenance, and management of the new systems, depending on the crops being grown. Traditionally they have been excluded from decision-making for major cash crop operations, but do participate in some activities related to cash crops.

Benefits

52. Women can be trained in new water management technologies as they are introduced. Their suggestions and comments regarding the new technologies will assist in making the appropriate local adaptations.

53. Women's work load in food crop production can be lessened by new/improved water mangement technologies. Intensive (household) gardens traditionally have been tended by women for production of vegetables, spices, and other specialty crops. They use these for their families and sell the surplus in local markets.

Having an improved water supply for their gardens can mean less time spent in carrying water from distant sources.

54. A surplus of production of food and specialty crops resulting from improved water management technologies can increase the income of women. Crops grown using the new technolgies can be the same ones the women are now growing in their gardens and thus can be sold in local markets.

VI. Short and long term policy issues

55. The concept of implementing a major program based on small scale water management technologies raises a number of issues for those involved.

Issues for everyone

56. The establishment of these technologies on a widespread scale will require a long time. Some of the benefits will not be realized for many years.

57. A major program of this type will not be inexpensive in the short run. However, it will be less expensive than large-scale, capital-intensive, state-managed irrigation projects.

58. There is a great need for trained people to assist in implementing the technologies.

59. A new philosophy of development is required, that is, more attention must be given to small scale agriculture and low-resource agriculturalists.

59A. Good design for small scale water management systems is a critical need. Standard designs are useful only as guides because of the site-specific nature of the technologies. Professionals involved with these technologies must be competent if transfer to other potential users is to succeed.

60. There will continue to be a need for storage of harvested crops to carry over through the years of low production or crop failure. These systems do not guarantee success under all conditions.

61. The opportunities for implementation of these technologies are many, but specific details on locations suitable for them are not available. Each has a need for certain social and physical environments. The areas of greatest potential should be selected for initial efforts (Dregne, 1983).

62. These technologies demand a higher level of management and maintenance than traditional methods. Users must be trained in new skills. Labor requirements may increase, and even in a subsistence economy, labor has an opportunity cost.

63. Populations may increase, especially in areas where crop production is marginal, raising the potential for accelerated deforestation and land degradation. This occurs because an increase in production and overall quality of life can increase fertility and survival in areas where most of the population now consumes less than the recommended minimum daily calorie requirements.

64. Concentrating water behind dikes or in terraces increases the need for spillways and/or controlled watercourses. Systems without provisions for excess flow are likely to fail.

Issues for the U.S.

65. A substantial level of support for a program in this area must be achieved. Little will be accomplished without a major, sustained effort.

66. The need for the program to be carried out over a long time must be recognized. The planning horizon for development assistance projects should be at least 10 years.

67. Adequate funding must be provided.

68. Pilot projects are needed in at least 3 locations to adapt the technologies to the different conditions of West Africa, East Africa, and Southern Africa. Newsletters, other publications, seminars and workshops can be used as effective linkages among the regional pilot projects and with other practitioners of the technologies. The pilot projects are needed to support adaptive research and also to serve for extension, demonstration and training purposes (Dregne, 1983). The pilot projects should deal with women's and men's issues related to the technologies.

69. Short courses to be provided in-country and at other locations are needed to increase the cadre of women and men who can serve as professionals and paraprofessionals in small scale water management technologies. Programs in U.S. academic institutions should be strengthened in this topical area (Matlock, 1985).

70. A regional project dealing with implementation of small scale water management systems is needed for Africa with subprojects in selected countries. This project, which will extend the results of the pilot projects described above, should serve as an umbrella for related work on other projects in Africa.

Issues for local governments

71. Land tenure changes may be required, for people will not invest time and energy in schemes to improve land for the benefit of others. Grazing and fencing rights also must be clarified.

72. There may be questions of water law and rights to be resolved. Allocation of water rights and scheduling of delivery or use of allocated water must be considered. Downstream flows may be diminished, at least temporarily, by a new/improved water management system, and rights of residents there must be considered.

73. A local cadre of trained professionals and paraprofessionals will be needed. Institutional backstopping in research and extension must be provided for them.

74. A continuing program of adaptive research will be needed into the future if governments are to provide effective technical assistance. Local support for such a program will be necessary for its long term success.

74A. Commodity prices will affect crop selection and the overall interest of farmers in investing in the new technologies. Local market supply/demand relationships must be studied before recommending specific crops. In most situations, there are food products being consumed which could be grown locally but are not. If grown locally with high economic efficiency, demand could increase because of a decrease in market price.

VII. Potential of these technologies

75. These technologies have a great potential. Each requires locations with specific environmental characteristics, but many such locations are known to exist.

76. In locations where they have been used effectively, productivity per unit of land has been increased substantially. A reconnaissance-level survey of the potential for water harvesting/runoff farming based only on rainfall and soils data showed that in many of the arid/semi-arid countries as much as 1/2 of the area is suitable for this technology (Bassiri-rad and Matlock, 1985).

77. Greater emphasis on these technologies must be given by all concerned to reach the potential.

78. Research should be conducted with a systems approach. More main-line agricultural scientists/engineers must be members of development assistance teams for small scale water management projects. The teams also must include other professionals to examine social, political, and economic issues. An overall feasibility survey of potential areas in Africa should be made as a first step.

79. Although these technologies take a low technology approach to agricultural development, there is no reason not to use the advantages offered by high technology methods. One example is the use of computer-based modeling of the various systems to assist in adapting them to local conditions, crops, and social systems. Development of improved crop varieties just for these systems also will be important.

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IX. List of acronyms and glossary

AWC--available water-holding capacity--the amount of water which can be held by the soil and which is available for plant use

PET--potential evapotranspiration--the amount of water expressed as a depth which would be evaporated and transpired from a grass crop given all the water it can use

RF--rainfall--the amount of precipitation which falls as rain expressed as a depth of water

SSWMS--small scale water management systems--water management systems under control of a farm family or group of families without full-time professional managerial or technical assistance

WMSII--Water management synthesis II--a USAID project aimed at improving water management around the world

FINAL DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

Soil and Water Management in the Humid and Highland Zones of Africa

by

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FINAL DRAFT

ABSTRACT

Spurred temporally and spatially by increasing population, lands under cultivation are expanding in the humid tropical and highland areas of Africa. As population pressures increase, without interventions in crucial physical, economic, institutional, and human factors, agricultural systems that were ecologically stable are now showing widespread environmental degradation. If left unchecked, potential productivity of the soil and water resources must decline. Low resource farmers have minimal ability to absorb costs needed for reversing the trend toward land degradation. Furthermore, as good conservation practices often benefit all segments of the national population, governmental and private organizations must value the goal of resource preservation sufficiently to subsidize activities needed to reverse current trends.

Sustainable agriculture for low resource farmers must run on renewable energy. Therefore, agricultural research and development must be reoriented within an ecological context. This will require project and research formulation to evolve to a longer term holistic approach. Meaningful data bases and monitoring of critical elements, such as soil erosion and food production, need to be established to provide planners with information to make rational decisions on environmental as well as political criteria. With ample labor available in rural areas, research oriented toward increasing crop yields through energy inputs instead of labor inputs needs to be reversed. With no major break-throughs in technology imminent, existing technologies have to be applied more creatively. One potential solution is to emphasize irrigation of humid instead of arid areas as a strategy of increasing food production within Africa.

ASSESSMENT OF LOW-RESOURCE AGRICULTURE IN AFRICA by

Laurence A. Lewis (Clark University)

Existing practices and technology - soil and water management

Overview

1. In response to generally increasing population growth, especially throughout the highlands of eastern Africa and the humid areas of western Africa, lands under cultivation for both food and cash crops have expanded both areally and temporally. In many environmental situations this expansion of agricultural (including grazing) activity results in a degrading land/water resource base under both traditional and exogenous practices. From a physical perspective, technical solutions are known for most conditions documented. But given the complexity of existing social and economic constraints found throughout Africa, purely technical solutions to most environmental situations have been inadequate.

2. The causes of this degradation are multifaceted and include physical, institutional, economic, and human factors. The following examples are indicative of general reasons for this phenomenon. Studies strongly suggest that lands being brought under cultivation, especially in the highlands, are more fragile than previous cropped lands in that they occupy steeper slopes and/or poorer soils. The direct transfer of existing agricultural systems into these less stable areas results in higher soil losses (Lewis, 1985). Another critical physical factor is the widespread

decline in the period under which lands remain in fallow. This prevents the soils from regenerating their nutrient losses (Nye and Greenland,1960). This results in an overall decrease in groundcover which conversely increases the potential for erosion.

3. Many governmental institutions intended to facilitate agriculture fail to accomplish their mandate. Among the reasons for this shortcoming are that many agricultural officers are hesitant to leave their urban headquarters for rural areas, where their skills could be utilized by farmers, except for short periods. And, when extension officers are in the countryside, support for their activities are often so underfunded that they cannot successfully accomplish their tasks. The net result is that most agriculturalists receive minimal assistance from institutional structures.

4. Some primary economic factors underpinning the 'static' long-term productivity of food production are administrative pricing systems and overvalued currencies that favor urban workers at the expense of rural workers. The net result of these practices is that in most areas there has been little incentive for farmers to adopt new practices that would be environmentally sound or to produce surpluses even if they could. Rates of investment into rural areas have been too low to maintain existing capital bases, let alone expand them (The Economist,1986).

5. Human factors also affect the mix of agricultural practices found throughout humid and highland Africa. To meet the increasing food needs in rural areas, resulting from increasing population, permanent groundcover is declining as more acreage is

required to meet this immediate food demand. Additionally, in response to government policies that have favored urban areas over rural areas, rural to urban migration is widespread. One result has been that rural populations in many areas are comprised disproportionately of the very young or old and female heads of households. As hand labor is dominant, this population mix has a lower potential to perform labor intensive practices. In some areas, such as in parts of Nigeria, this has resulted in labor shortages during crucial agricultural periods inspite of overall high rural populations.

Specific Practices and Technology

6. As water is the critical erosional agent in humid and highland Africa, the control of soil loss requires effective water management. Conversely, accelerated soil erosion results in larger sediment transfer and higher deposition rates. Increases in these two factors decrease potential water use in affected areas. Thus soil conservation practices should be considered a critical component in water management planning.

7. The two general principles underlying soil/water management practices are: (a) the maintenance of infiltration rates at high enough rates to reduce surface water runoff to minimal amounts and keep runoff velocities low; and

(b) providing a safe (nonerosive) disposal of overland flows when precipitation exceeds the infiltration capacity of the soil (a high percentage of rainfall events in humid and highland Africa exceed soil infiltration during at least a portion of the rain event).

8. Almost all soil and water management practices, both traditional and modern, either utilize engineering methods and/or soil-conserving vegetation to accomplish these two general principles. Common engineering methods always involve some movement of the soil, and as in the case of terracing actually alter the topography. They include various tillage, drainage, and terrace practices. Soil-conserving vegetation methods attempt to protect the soil and increase infiltration by providing a complete groundcover that intercepts rainfall, thus lowering the intensity of the rain before it strikes the soil. Perennial crops, intercropping, and mulching are the major soil-conserving vegetation practices.

9. Tillage practices all manipulate the soil with the intent to improve the soil for plant growth. But intensive tillage of tropical soils generally leads to rapid breakdown of soil structure and accelerates the decomposition of organic matter (Constantinesco 1976). Thus for many of the environmental conditions found throughout the humid areas of Africa, the strategy of minimum tillage needs to be encouraged. Furthermore it is a practice that reduces labor inputs during the planting season.

10. Common tillage practices: Plowing, hoeing and other forms of cultivation that breakup the soil will temporarily increase infiltration and lower runoff. However this effect is very transient. In fact, by breaking up the soil peds into smaller

components, the soil can become less permeable and more susceptible to erosion during the growing season. Therefore this practice should be kept to the minimum needed for seedbeds and weeding. Furthermore, while plowing or hoeing on the contour can be a simple conservation practice, it is effective only on gentle slopes. On steeper slopes contouring can actually result in higher soil losses than flat cultivation (Kowal 1970).

11. Ridging (channel terracing) is the construction of alternate furrows and ridges of soil along the field contour. When small basins are created within the furrows it is called tied ridging. To be effective, the ridges must be accurately aligned on the contour, a difficult task when the construction is done with hand hoes. When built improperly (not exactly on the contour) ridging encourages channel formation that can increase soil losses. These practices are particularly effective in areas not subject to high-intensity rains, on freely drained soils, and in gentle slopes. Along the drier margins of the humid areas, such as the Lake Region in Tanzania where soil moisture retention is crucial for good harvests, these practices have increased yields. Results from 14 trials between 1939-46 showed that cotton, maize, and sorghum yields in plots having ridging were almost always higher than in flat cultivated plots. The only exceptions, 1942 and 1945, were years having above average rainfall (Constantinesco 1976). In the drier years, the yields from plots which were ridged were especially impressive as they represenated the difference between crop failure on the flat plots and economic success on the plots ridged. Spectacular increases in cotton

yields were documented by Peat and Prentice in eleven trials from 1945-47 in Tanzania, and by King in Nigeria during 1960 on plots ridged compared to flat plots during dry years (Constantinesco, 1976, p. 55).

11A. Even when constructed properly, under less favorable situations as during heavy rains, tied ridging can cause overtopping which often breaks a succession of ridges resulting in either deep rills or gullies. Under these circumstances, runoff control needs to be improved through the addition of other practices such as drainage improvements or terracing. As all forms of ridging are ephemeral and need to be constructed either seasonally or annually, they are labor intensive and require proper alignment during the advent of each planting period.

12. Drainage Practices: As humid areas experience more frequent and longer periods of moisture surpluses, drainage is a widespread effective stragegy for improving agricultural lands in the humid climates. In areas of gentle topography, soils require drainage either because there is a high water table or because physical properties of the soil hinder the infiltration of water to depths below the root systems of the crops. To control soil erosion, many lands need drainage to reduce runoff. Topographic conditions for this circumstance usually are moderate to steep.

13. To lower water tables, subsurface drains inspite of numerous advantages are rare largely because they are costly and difficult to install. Open drains are common because they are less expensive and easier to build than other drainage works. However they have many disadvangages including: (1) taking up agricultural

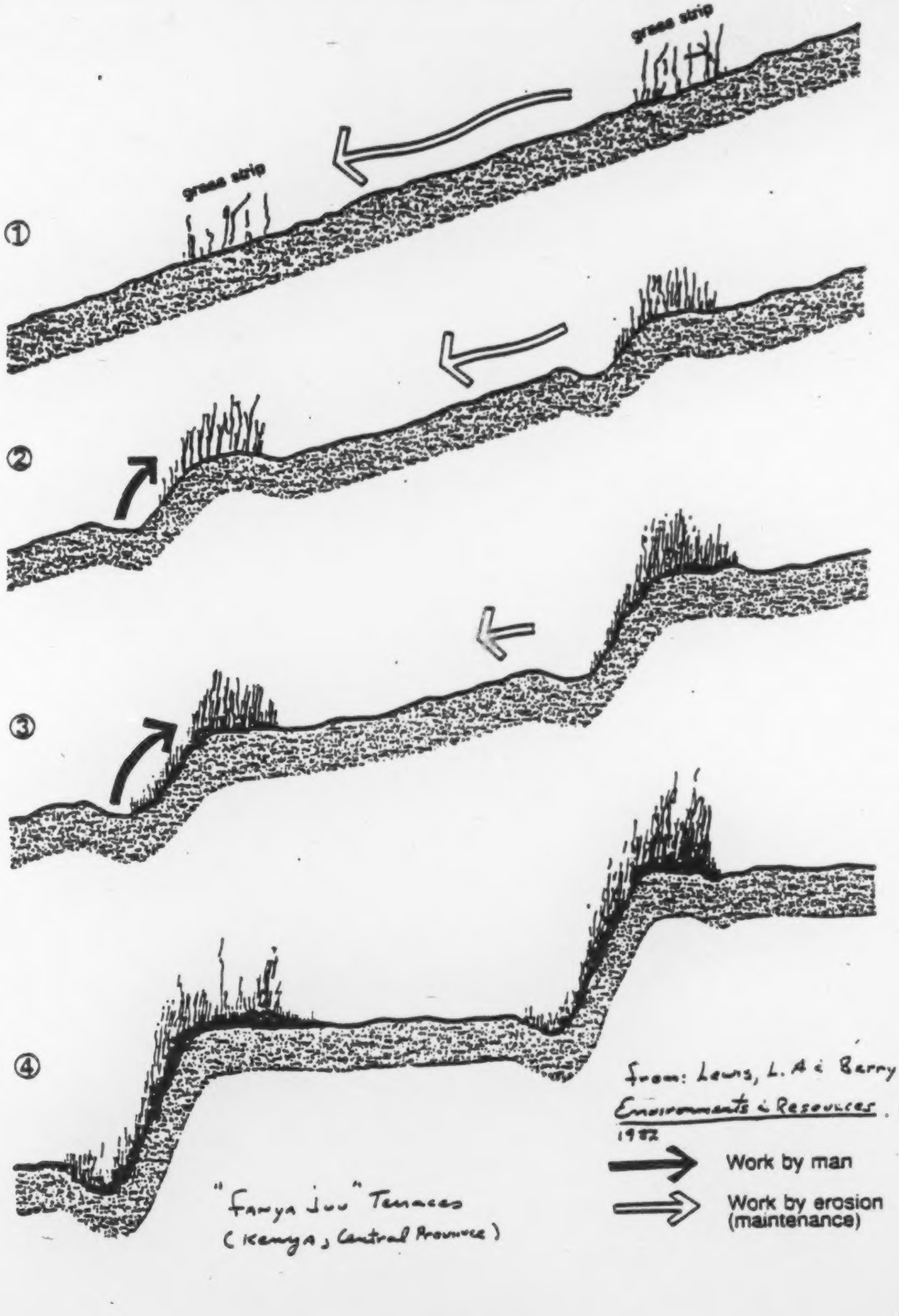
lands, (2) harboring weeds and rodents, (3) requiring high maintenance, and (4) creating favorable conditions for numerous waterborne diseases if stagnant water remains within them.

14. Draining areas having high water tables, such as along valley bottoms, can substantially increase the potential area of arable lands. In Rwanda where rural population densities are high, artificially drained lands along valley bottoms are widespread and contribute significantly to the country's food production. Additionally as water tables remain close to the surface in these low lands during the drier seasons, these zones often remain in production when juxtaposed lands due to soil moisture deficiencies are idle. This additional area of food production minimizes the need for storage with its associated food losses and extra costs, during the drier portions of the year.

15. Due to impermeable soils, areas of impeded drainage must utilize different strategies than lands with high water tables. Improving the soil moisture conditions in these areas requires increasing runoff from rain events and hence lowering the amount of water available for infiltration. Generally this involves some type of topographic modification such as cambering the soil with open drains between the convex soil units (Robinson 1959). Because the soils involved usually have low infiltrations, perennial or annual crops are usually grown under these conditions. This minimizes the silting of the open drains between the cambered soil beds. The utilization of plowing facilitates the construction of these soil beds but hoeing can also be utilized.

16 Drainage associated with soil erosion control always attempts to transport runoff at a non-erosive velocity to a suitable disposal point. This is particularly crucial since most drains are not lined and when poorly designed often become a catalyst for gully formation. Dimensions of the diversion channels need to be large enough to have sufficient capacity to handle large storms (five-fifteen year frequencies). In reality, most drains are underdesigned for a multitude of reasons including poor rainfall records, size constraints due to land scarcity (small fields), costs, and shortage of technical personnel to design and survey the drains. Therefore soil erosion control using this procedure is often ineffective.

17. Terracing: On steep agricultural lands, if overland velocities are not reduced, excessive erosion often results. Terraces are one approach for removing surface waters at non-erosive speeds by shortening slope (field) lengths and decreasing the cultivated portion of the slope. In humid areas it is important to prevent excessive infiltration inorder not to initiate mass movements. Thus adequate drainage must be provided in the design of the terraces to offset the effect of the lower field slope. The least expensive and simplest manner of constructing a terrace is : (a) to leave vegetated strips of noncultivated land spaced across the slope between cultivated areas; and (b) construct a cutoff drain immediately along the lower edge of the noncultivated strip. When done properly erosion on the upslope portion of the field and deposition along the edge of the vegetated strips will result in terraces over a five to six year interval (Wenner 1977). The



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"Fanya Juu" Terraces
(Kenya, Central Province)

resulting terraces, known as 'fanya juu' in Kenya (Fig. 1, Lewis and Berry 1987), have reduced soil erosion in the Kenyan Highlands (Lewis 1985); but more importantly, from the farmers' perspective they increase crop yields. In Machakos (Kenya) maize production increased 50 percent after the introduction of fanya juu terraces. In the high rainfall area of Nandi (Kenya) again maize yields increased on the terraced lands (Wenner 1983, p. 306). These increases likely result from the combination of the soil saved and the water and nutrients retained by terracing.

18. In contrast to the utilization of engineering methods in soil and water management, the use of soil conserving vegetation requires minimal manipulation of the soil. Probably the single most effective land management practice for minimizing storm run-off is mulching, not engineering methods (Leopold and Maddock 1954). Covering the soil with crop residues such as straw, grasses, or leaves to fields under perennial (eg. coffee) and semi-perennial (eg. bananas) crops is almost always associated with very low soil losses even on steep slopes (Lewis 1986). Even when a soil-degrading crop (eg. corn) occupies a field, soil losses are minimal when mulching (including stubble and leaves) is applied (Lal 1977).

19. In a general survey of soil erosion in the tropics, El-Swaify, Dangler, and Armstrong (1982) emphasize that maintaining adequate cover is probably the best means of minimizing or preventing soil erosion. Adequate cover is particularly important at the start of the rainy season in the wet-dry humid tropics and always important in areas of steep slope. Thus in descending

order, generally the best soil-conserving crops are perennial ones followed by annual and seasonal types. To compensate for the lower groundcover capabilities of numerous plants, intercropping and mulching are good management practices.

20. A significant percentage of African farmers understand the need for soil conservation and good water management for the long-term future use of their lands. But, because of immediate needs, they rarely will adopt them unless convinced that new soil/water management practices will result in increased yields today rather then in the remote future. Given the general constraints of capital, labor, skills, institutions, and infrastructure existing for most low resource agriculturalists, soil-conserving vegetation methods should be emphasized as the first approach for improving soil and water management in their agricultural systems. However in areas of steep slopes (~15 degrees or greater), both vegetation and engineering methods need to be integrated for effective management of soil and water resources.

Implementation ("how-to's") of soil and water management

21. Given that the overwhelming majority of the rural population earns its livelihood in farming, rural development in sub-Saharan Africa is ultimately a question of being able to improve the agricultural system. If the management of the soil and water resources is to be successful (renewable resources remain renewable), it needs to be conceptualized within this framework. Clearly, agricultural production is subject to the constraints and

potentials of the natural resource system. But, except for the purely subsistent farmer, the nature of the marketing system has equally important implications on the specific crops grown. This is an important factor limiting potential soil-conserving vegetation options.

22. Similarly, the use of the natural environment and the manner in which economic activities are conducted are a function of attitudes, values, beliefs, and perceptions. It is for this reason that technical assessments of soil/water management strategies need to be evaluated in terms of their social-cultural-institutional context as well as the traditional physical and economic perspectives (Table 1). Table 2 illustrates some other applications of soil/water management practices with regard to OTA's Principles and Concepts.

23. Low resource agriculturalists usually must concern themselves with their short-term survival. Yet, it is difficult to ensure long-term economic and environmental sustainability (principle G) without increasing some short-term risks. The encouragement of utilizing soil-conserving vegetation as a strategy for improving environmental sustainability could reduce immediate returns (principle C). For example the increase use of mulches often results in less fodder available for livestock. Most soil conservation efforts, especially where the problem is already severe, require reduced land use for an initial period, hence lower agricultural production. Local participation (principle H) on the part of farmers and local officials is particularly important when resource conservation is an important goal. Because of the time

period often required to accomplish this aim and the likely decrease in short-term income resulting from some of the new land/water management practices, farmers must support the program if it is to succeed.

24. However, even with farmer support, means must be found of dealing with this initial income reduction burden. Small farmers, given their marginal incomes, cannot absorb these recurrent costs. Furthermore, apart from the on-site benefits of improved soil and water practices, downstream reduction in damage caused by excessive soil erosion (e.g. reservoir sedimentation) may be more important in some cases than the soil loss. There is no reason why the farmer should be expected to absorb all the costs associated with the needed remedial measures since many other segments of the population benefit from improved soil and water management (Hudson 1983). For this reason a project's activities must be ones that all the beneficiaries value to a sufficient degree to assume their short-term costs. Subsidies for work carried out by the farmers achieve the objectives of countering the temporary loss in income associated with some of the new practices and helps to ensure farmer interest in the changes (Coffey and Lewis 1984). Thus governmental or private organizations must value the ultimate goals of the activities enough to finance or subsidize them (Honadle and Vansant 1984).

24A. In Central Province, Kenya, a soil conservation project concerned with reintroducing terracing (previous terraces built during the colonial period had been largely destroyed) to the small farmers and funded by SIDA (Swedish) has continued after the end of external funding, albeit at a slower rate. The reason that the momentum initiated by this project has continued is that the farmers are aware of the economic benefits resulting from the reduction in soil erosion. The result is that farmers themselves are willing to do the physical work needed for terrace construction. The Kenyan government only needs to provide the technical assistance needed in aligning the terraces.

Short and long-term policy issues relating to technology

Identification of issue

25A. Soil erosion and land degradation is by no means limited to Africa. Since the 1930's the U.S. Federal Government has spent over $15 billion to finance an array of soil conservation programs (King 1981). Despite this investment, soil erosion continues to be a problem in many areas. Estimated sheet and rill erosion for U.S. cropland is 4.8 ton/acre/year. Large areas in eastern Washington, the lower Missouri River Valley, and the middle and lower Mississippi Valley are experiencing erosion rates in excess of 10 t/a/y (Lee 1984). If you accept the belief that on average 5 t/a/y is an acceptable soil loss (soil tolerance concept), about 50 to 75 million acres of U.S. cropland is exceeding this value (Lee 1984). By inference, this land is degrading.

25B. Probably the most successful soil conservation practice in the US has not been engineering practices (i.e. contouring, terracing) nor crop management practices. It has been taking high risk lands out of production. Often the decrease in soil erosion has not been in reponse to explicit soil conservation projects, but to agricultural programs attempting to reduce our grain surpluses (i.e. soil bank). The Food Security Act of 1985 recognized this by including a provision for placing highly erodible cropland into voluntary (farmers are paid for doing this) conservation reserve for 10 years. Unfortunately this is a viable alternative only for countries having agricultural surpluses and ample good cropland; a condition that is rather rare in most African countries.

25. Urbanization has accelerated since independence in most African countries. Nevertheless, the vast majority of sub-Saharan populations' livelihoods are still directly dependent on the land for food, shelter, and energy (firewood). If the soil and water resources are to continue to have the potential to meet future production demands, viable conservation strategies must be developed and rapidly implemented (World Bank 1981). In spite of over two decades of post-independence conservation projects, accelerating soil, vegetation, and/or water degradation exists in almost every African nation (Brown and Wolf 1984). Even in Kenya, which is often cited as having the most successful soil conservation program in Africa (Wenner 1983), there is good evidence, both direct and indirect, that a sizable percentage of productive highland areas are experiencing high erosion rates. Approximately 26 percent of some of the best Kenyan agricultural lands in Kiambu

and Murang'a have soil losses in excess of 12.5 mt/ha/y (Lewis 1985).

26. Some reasons for the overall lack of success in arresting the degradation of the natural resource base are poor project designs, political constraints, poor data, abilities of planning institutions, and the low priority of environmental issues until problems become acute. Even when specific projects are 'successful' in regard to the scheme's soil and water management goals, often the general problem of regional environmental degradation continues.

Project design

27. Perhaps one underlying design flaw in many of these 'successful' schemes is that they were conceptualized within the very narrow confines of the immediate project. However project boundaries usually are independent of the components comprising the wider environmental context. Offsite project variables and impacts are rarely considered. Using the project boundaries, analyses usually internalize benefits in a quantifiable way and externalize costs. Many costs cannot be easily traced to a specific project, and for this reason rarely are included in project assessment. Yet these exported costs can frequently produce serious areal environmental consequences.

28. Another striking feature of most development projects is that they are sectoral in nature. Because human and physical systems are all too often not seen as part of an interactive system, environmental degradation usually results. Unfortunately once ecological deterioration reaches crisis proportions, usually it is expensive (perhaps not even cost effective) to reverse and there

are few remaining viable options (degrees of freedom). Land degradation has resulted around numerous wells and water reservoirs that were built to improve the reliability of water supply for the local_inhabitants. In many cases it is economically not feasible to attempt to bring these areas back into production (Murray-Rust 1972). For this reason, assessments and monitoring of the environmental status of land/water resources need to be a high priority in all economically important areas, even when no problems are perceived to exist.

29. Compounding planning implementation in agriculture, land and water management is usually parceled out among an array of ministries and agencies within African governments. Frequently these departments have competing agendas. The tendency to work at cross purposes is also common within international aid organizations.

Political constraints

30. A conflict often exists between the short-term goal of increased agricultural outputs and water development with the long-term objective of preservation of the land and water resources. This conflict exists to the greatest degree in heavily populated highlands and along the drier margins of the humid tropics. In both cases lands are stressed and the quality of the land and water resources deteriorates.

31. In the abstract, most politicians and bureaucrats support conservation. But in general because benefits from such programs become evident only years after they are initiated, and then only if properly designed and implemented, funds are usually allocated

for rural development into tangible projects. Thus engineering and public works components, such as road construction, terracing, and perhaps tree planting are usually stressed. Human infrastructure, including organization and maintenance components, are generally downplayed. The bias for immediate results is logical since rarely if ever have soil and water projects conceptualized in a long-term perspective won votes for the politician or promotion for the bureaucrat.

32. Furthermore, because low resource farmers also must think in the short-term for their survival, conservation projects are difficult to implement. They must satisfy the immediate needs of the small farmer, bureaucrat, and politician while improving the status of the land and water resources over the long run. Successful soil and water management requires long-term commitments. Development annals are filled with cases of resource oriented projects that have left minimal positive imprints even after five or ten years of primary project funding (Honadle and Vansant 1984). In fact, when engineering works such as terracing have represented major foci of projects, the lack of integrating the establishment of an infrastructure to provide continuous maintenance after the construction phase often results in accelerated environmental degradation (Chakela 1981).

33. Clearly most project designs in water and land management should be conceptualized in a long-term framework. Additionally, they need to satisfy two constituencies (the government and the farmers), if they are to succeed. Governments must see benefits accruing to them, and at the same time not feel threatened by

them. Government legislation can encourage or discourage good conservation practices, but legislation by itself has not worked in Africa. Complete involvement by the farmers are required for successful management of the land and water resources. In practice this means that some type of community organization is required. Project conceptualization must incorporate both the 'bottoms up' and 'top down' approaches.

Data constraints

34. Management of soil and water resources, as developed in the United States and Europe, usually require a data base that is lacking in Africa. In addition, the critical parameters affecting the status of the soil and water resources in the middle latitudes are not necessarily the same in the tropics (Lewis, 1981, Roose 1977). Yet the general assumption has been that they are closely identical. Furthermore, because of the wide diversity of meteorological and geomorphological conditions in tropical and highland Africa, what is valid in one location, such as Cameroon, is not necessarly correct in another area, such as Zaire, even though they are broadly classified within a single environmental category (Humid Equatorial Lowlands).

Discussion of issues

35. Considering land and water resources as national assets, benefits from their use and further development need to be

assessed in a long-term framework. However before meaningful monitoring and assessment of these resources can occur in the humid and highland tropics, significant deficiencies in methodologies and data need to be ameliorated. Rational land use, both from the production and conservation perspectives, requires a valid methodology of land evaluation for the environmental conditions of Africa. The land classification system (LCC) developed for conditions in the United States (Klingebiel, A.A. and Montgomery 1966) and often applied to tropical areas (Higgins, G.M. 1977) is generally not suitable for African conditions. For example, according to the LCC, all slopes greater than 7 degrees fall outside lands suitable for cultivation. This is too restrictive for Africa where manual labor and not machinery is utilized. Also, other aspects of the farming systems, precipitation patterns, and soil attributes differ greatly from the conditions for which the LCC was conceptualized. Transferability of other existing land classifications is equally risky. Rarely do conditions exist in Africa that are identical to the areas for which other classifications were designed.

36. Both the small size of most farming units as well as the dispersal of the fields (especially in Francophone Africa) compound the problem of developing strategies that will increase the agricultural returns from individual fields while improving or maintaining the soil and water resources. Nature does not recognize the sovereignty of field boundaries. Thus to minimize erosional and runoff problems, it is necessary to co-ordinate all farming practices existing on the hillslope system. The actions

of a farmer practicing good techniques would likely be negated or minimized by other farmers on the same hillslope system unless they also adopted good farming practices.

37. For conditions that exist in Africa, what are good farming practices? Many technical problems need to be solved before this question can be answered. On the steep slopes cultivated in the highlands, sometimes in excess of 100 percent, because of the intensity and amount of many rain events, there are no existing practical solutions to control runoff (Slope percentage is determined by the ratio between the vertical drop to the horizontal distance. Thus all slopes greater than 45 degrees are in excess of 100 percent. The agricultural sciences generally use percentages while the earth sciences use degrees to describe slope.). Agroforestry, often cited as a new agricultural system solution, suffers from the low yields in annual and seasonal crops. In the humid tropics, tree cover results in shade that inhibits plant growth. From an environmental perspective, agroforestry is potentially a viable approach. It remains to be proven that economic development, except at the most basic level, results from this practice.

Agricultural Research

38. As largely practiced to date, agricultural research is unlikely to find effective solutions with widespread applications for increasing agricultural outputs while preserving or improving the land and water resources. Reviews of agricultural research conducted at international research stations and local research institutes indicate that agricultural research in Africa almost

always is conducted under conditions that do not replicate the constraints under which small farmers must operate (Mongi and Huxley 1979, El-Swaify, Moldenhauer, and Lo 1985).

39. Almost all research is conducted as piece-meal experiments rather than integrated within the constraints of small farmer agricultural systems. That is, most research has been oriented toward single dimensional problems that are relatively easy to solve, rather than taking a holistic approach focusing on long-term solutions. Often this results in solving specific problems without concern for feedback resulting from the technical solution. For example, research substantiates that mulching is an effective erosion control. However by increasing the use of mulches for erosion control, available feed for livestock is usually reduced. One result of this reduction might be overgrazing in other areas. This could offset the gains of erosion control on the mulched fields.

40. The processes affecting both the physical and human systems of agriculture operate spatially. For this reason alone, if it is to solve the problems of the real world, land and water resource management research needs to be conceptualized within the framework of agricultural systems and not sectorally. The sum of the parts is less than the whole with regard to relations among agriculture, environment and development.

Project Design

41. Agricultural development projects in both their initial and implementation stages need to be environmentally sound. Perhaps the two underlying design flaws in most agricultural based

projects are: first, they are conceptualized within the very narrow confines of the immediate project; and second, the time frame for projects are too short to succeed in fundamentally improving agriculture while installing good land and water management practices. For the first case, both project onsite and offsite implications must be considered during the design, implementation, and evaluation phases of any project. This means that not only should the scheme's direct and indirect costs and benefits be evaluated, but its impacts on the greater area must also be included in any assessment. This implies that traditional project cost-benefit estimates must be expanded. Along with the short-term and long-term economic effects, appraisals of environmental components, such as soil conservation, need to be incorporated into project assessment (perhaps multi-objective resource analysis is a valid alternative to traditional cost-benefit criteria in assessing agricultural projects).

42. Since small-scale agriculturalists principally rely on local inputs, their land and water resources must remain viable with minimal external inputs. For this reason alone, agricultural development projects must be concerned with resource maintenance. Environmentally sound agricultural development must synthesize a complex set of factors. First there are the plethora of human variables including population growth, land tenure, organizational and educational deficiencies, economic constraints, and infrastructural weaknesses. Second, superimposed on these human factors are a host of physical elements including soil, vegetation, geomorphic, and climatic attributes.

43. For successful development, activities and relations within and between the physical and human domains must be altered including rearrangments of traditional activities and new inovations. This requires time. Existing funding periods, and thus committments of most aid organizations, are too short to permit the structural changes required for meaningful agricultural change. Furthermore, if 'real' benefits cannot be almost immediately (generally) substantiated, projects are terminated or curtailed before meaningful long-term benefits accrue. The bias of the quick fix project design is further exacerbated by the staffing policies of numerous aid organizations.

44. In most international organizations, two to four year tours of duty are common. Some negative ramifications inherent in short term appointments are that projects developed by previous administrators often become low priorities with a change in staff. Second, if benefits of projects are conceptualized in a long-term framework, tours of duty are completed before project success is evident. Promotion of individuals are less likely, if activities are not evaluated as successful during their term of duty. This encourages project conceptualization within short time frames. Third, much time is wasted within agencies reorienting new personnel to new country situations. All too often, just as individuals become able to make significant contributions to agricultural development programs they transfer or are transferred to new locations. For effective programs in many aspects of agriculture, longer commitments are required in both funding and personnel.

Data Needs

45. For most of Africa, including the high potential areas, data on the land and water resources as well as agricultural production are highly suspect. Systematic collection of data or the continuous monitoring of natural resource base phenomena rarely exist in any area, yet alone at regional or national scales. Thus data needed for planning purposes are estimated from indirect observations, eyeball assessments or individual specific studies having limited temporal and areal scope. The danger of extrapolating inaccurate trends from these types of sources are high. Hence policy decisions based on this information base are risky.

46. Permanent monitoring programs, including the assessment of critical environmental components associated with agricultural production, need to be established. Only if such programs are implemented will reasonable inventorial data be available to make national and regional cost-benefit calculations. It is from such analyses that the design and implementation of effective agricultural projects will result. The maintenance of a nation's soil and water resources is a prerequisite if long-term agricultural development is to occur. Thus effective cost-benefit analyses must include not only the traditional economic inputs, but incorporate environmental components in their assessment too. This means that it is necessary to develop methods of expressing soil conservation, water quality, and other environmental variables in terms which will permit their incorporation into economic models. Preventing the mining of renewable resources, such as excessive soil erosion, is as important as immediately

increasing cash profit if agricultural development is to occur (Hudson 1983). One such program that has provided a start in obtaining the needed information to integrate economic and environmental variables is the Agricultural Survey of Rwanda (funded by USAID).

47. Given the urgency for developing a meaningful environmental data base in Africa, along with the costs (including human resources) and time demands associated with monitoring and data collection, these programs need to be conceptualized using valid sampling designs. The framework adopted for the Rwandan Agricultural Survey (Ministere de l'Agriculture 1985) is one possible approach. Besides using a sample strategy based on theoretical considerations (confidence intervals of extrapolations can be determined), an infrastructure (Bureau) has been established within the ministry to continuously collect and analyze agricultural and environmental data.

Development of Existing or New Lands

48. Without agricultural planning, small farmers usually respond to mounting population pressures by expanding into new lands, largely marginal. Various sets of responses usually occur as farmers attempt to replicate their previous agricultural system on these new lands. In general, the net response is the area degrades environmentally, lowering its overall potential productivity. Additionally, negative spatial responses occur beyond the immediate area, such as increased flooding and siltation. Thus, environmental degradation at the local, regional, and national levels is likely to accelerate if small farmers are left to

'natural forces' for their survival. For this reason alone planning interventions are necessary.

49. One planning strategy is to open new lands for agricultural settlement. Another is to attempt to make existing lands more productive. In most of highland and humid tropical Africa, the better agricultural lands are probably already in production. Therefore, new settlement areas often will have a lower potential and be more prone to environmental problems than the older established areas. This appears to be the case in the densely populated Kenyan highland areas (Lewis 1985). Furthermore, new areas often lack most infrastructures needed for successful agriculture; and, a sizable proportion of small farmers, if given the choice, would rather remain in their old areas. Yet a very large proportion of agricultural schemes, even in the initial stage of formulation, are conceptualized to develop new areas without evaluating the option of improving existing ones. Perhaps this is an additional reason why international aid has not resulted in significant impacts on improving agricultural outputs within humid and highland Africa.

Speculation on the Potential of Technology

50. Low resource agriculture, to be sustainable, must run on renewable energy such as solar energy compared to chemical fertilizers. Soil physics research indicates that adoption of no-till or low-till practices would be a good conservation practice.

Within the context of sustainable agriculture dependent on renewable energy, at first glance it appears to have a high potential for adoption by small farmers. However, as developed to date, these practices require chemical herbicides. As a result, they likely have minimal potential for widespread adoption in their current form. Yet, for sustainable agriculture, environmental degradation must be arrested. From the physical perspective, agricultural systems that approximate an area's natural ecosystems will likely be best. That is, agricultural development, and hence research, should be conceptualized in an ecological context.

51. For the humid tropics, this implies that strategies that minimize the monoculture of seasonal and annual crops must be developed. The 'couloir' system (Ruthenberg 1971), a large-scale attempt to regulate and improve shifting systems in the Belgian Congo, represents one approach to incorporate traditional agricultural systems into more productive ones while maintaining a large degree of the natural ecosystem's diversity. "The corridor system was an attempt to establish a commercial agricultural system, using the shifting agriculture attributes of cultivation-fallow, that was clearly environmentally viable in rainforest areas.

51A In the corridor system, a large (1,000 - 2,000 ha) area was divided into a series of strips. Strips of about 8-12 ha were then allocated to individual families. In any given year, 1-2 ha were cleared or cultivated, wtih the remainder of a family's strip remaining in fallow. Plots allocated to families were juxtaposed so that, in each year, a cleared corridor ran through the forest.

Between each strip cleared, alternating strips of forest were preserved to provide shade and seeds for the regeneration of the cleared lands when they were no longer being cropped.....In addition to integrating the agriculture into the economy, the permanence of the area made the construction of roads to transport the products to market feasible. Given that the corridor system was meant to be an integrated farming system, coordination between the individual farms was required in terms of crops grown in each strip. Thus, in contrast to the traditional system of shifting agriculture, management for the whole paysannat was required (Lewis and Berry 1987)."

51B The total collapse of the couloir system after independence illustrates the need to integrate both physical and human systems into any planned intervention in resource management. Maintenance of the system required administration from outside institutions to coordinate marketing, credit and planning. While the physical constraints of the continuously humid environment were relaxed by proper technological interventions, the couloir package failed because the technical changes were unacceptable and unabsorbable by the local populace (includes the national government).

52. Sustainable agriculture, especially in the highlands, probably necessitates conservation practices. They are required not only to preserve the resource base of the small farmers, but to protect other development and existing projects, especially those concerned with water resources. Long-term economic incentives are likely required to both facilitate the adoption of conservation practices as well as to insure their maintenance.

This will require policies to be formulated that remove the total direct costs of conservation from the producer to the public at large.

53. With almost ubiquious population growth in rural areas, there is a need to absorb a larger percentage of the growing labor force into productive activities. Otherwise the expansion of agricultural activities onto evermore fragile lands and migration of a proportion of the surplus rural population into urban areas will continue unabated with all of the associated physical, social, and political ramifications. To address this issue, agricultural research needs to be reoriented from the primary use of energy as the mechanism for increasing yields to the use of labor inputs. This change in emphasis cannot be conceptualized solely as a technical problem since palatable methods for increasing labor inputs must also evolve. This is an example of why a holistic research approach is needed to provide fruitful results. The increased use of labor must be compatible with other demands.

54. To develop and implement effective land and water management strategies geared to improving low resource agriculture requires an accurate data base that is almost nonexistent in both humid and highland Africa. Basic demographic, production, and environmental data are lacking for most areas. Methodologies and programs to circumvent this shortcoming must be initiated. Without information, the risk of implementing incorrect programs increases. Because of financial, manpower, and temporal constraints new approaches in data collection are required. The refinement of satellite resource sensors, such as Landsat TM (NASA 1984) or

other types of remote sensing, to provide information useful for the continuous monitoring and assessment of land and water resources is one likely valid approach for obtaining broad regional data.

55. Additionally there is a need to develop the capabilities of governments to collect and analyze meaningful agricultural data systematically. The development of analytical capabilities, resource assessments, standards and implementation of conservation policy are national responsibilities. For them to be successfully implemented, governments themselves must make them a high priority. International organizations can facilitate the process, but outside funding without long-term committments of local government does not work. The lack of real governmental commitment toward low resource agriculture, has been and likely will continue to be a major impediment to successful applications of technology in most African countries.

56. Meaningful extension work is a prerequisite for the reorientation of farming and grazing systems toward a sustainable agricultural mode. Through extension work, data can be collected, the diffusion of innovations can reach the farmers, and educational programs, including demonstration, can be instituted. In many countries, the extension infrastructure already exists. But the reality of the situation is that extension services are a low priority within most agencies. They are largely ineffective as they are underfunded and understaffed. When financial shortfalls occur in agricultural ministries, extension services are one of the first areas to experience budget cutbacks in spite

of being initially underfunded and crucial to the theoritical aims of most departments. A fundamental requirement for improvement of low resource farming in Africa is an increase interest in providing extension services to farmers.

57. Because the boundaries of the physical and human systems affecting agriculture rarely coincide, successful land and water management require community organization. But community organizations whose interests are the low resource agricultural farmer will probably be viewed with skepticism by most governments. In general, small farmers are of little political interest to urban based governments. But as these governments usually show interest when aid funds are offered for agricultural purposes (probably as much for the hard currency as for the projects themselves), there is an opportunity for concerted pressure by international aid agencies to secure significant action. But there are difficulties in that rural based projects are areas of intense competition among aid agencies with minimal coordination among the interested parties.

58. Furthermore, agricultural and rural based projects must fit into a regional or national development strategy if they are to be successful. At the minimum, markets must exist for agricultural products that are encouraged for conservation reasons, especially in urban areas. Therefore there is a need to coordinate, to some degree, agricultural (rural) and urban projects. Even within single aid agencies, let alone among different agencies, the goals of the urban and rural sections are often at cross purposes. The lack of significant coordination within agencies as well as the

generally short-term tour of duty of individuals working in aid agencies (paragraph 44) appear to be one of the easier changes to implement for increasing the likelihood of success in development activities.

59. No major break-throughs in technology appear to be imminent that will guarantee increasing crop and livestock production for low resource agriculturalists while at the same time creating sustainable agricultural systems. Given the immediate need to improve the agricultural situation, existing technologies have to be applied with greater imagination and synthesis. For example, the expansion of irrigation into humid and highland areas would likely be more cost efficient in increasing agricultural yields and more environmentally sound than its application in arid areas. Also, it would not require population resettlement. Furthermore, irrigation could be conceptualized as a conservation practice in both the seasonally humid and tropical highlands. This is in contrast to the environmental degradation, such as salinization, that is associated with many arid land irrigation projects. Yet almost all publicly funded irrigation schemes in Africa are located in dry areas.

60. In humid areas, there are short periods of small soil moisture deficits in most growing seaasons. During these intervals, vegetation is stressed and lower yields result. Through small supplements of irrigated water during these brief periods, the soil moisture deficits could be eliminated; and, crop yields would increase. As less irrigated water is needed per land unit in humid areas and it is more available than in drier areas,

smaller engineering works would be required for water delivery and larger areas could be irrigated per available water.

61. Water availability determines the growing season in the tropics. Therefore, the application of irrigated waters at the advent of dry seasons would extend growing seasons. This would increase the potential pool of crops that farmers could successfully grow. New crop options would exist. Therefore small farmers might be able to substitute higher value crops and obtain a greater income without having to areally expand their operation.

62. Finally, soil erosion potential is greatest when soils are bare and unprotected from direct raindrop impact and overland flows. For this reason soils are potentially most susceptible to erosion at the beginning of rainy seasons. If fields would be irrigated before the rains commence, planting could occur earlier. This would result in an existing groundcover, provided by the crops, to exist prior to the start of precipitation. Soils would be protected to a far greater degree than under current practices. In many ways, this duplicates the natural environmental conditions (no bare soil exposed to rains) as they existed prior to the introduction of annual and seasonal crops. This is irrigation use conceptualized as a conservation practice (paragraph 50).

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Table 7.1 Percentage of land ~~area~~ receiving selective amounts of annual precipitation ~~rainfall~~ in four out of five years.

2pt

Rainfall (mm)	Kenya	Tanzania	Uganda	East Africa
<500	72	16	12	35
500–750	13	33	10	20
750–1 250	12	47	72	41
>1 250	3	4	6	4

1pt

2pt

DRY — (arid or semi-arid)

Subhumid to humid

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LOW-RESOURCE AGRICULTURE IN AFRICA

Low-Resource, Small-Scale Irrigation in Africa

by

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I. ABSTRACT

1) There are two basic classes of low-resource irrigation technology in Africa--gravity and mechanically fed. The two main gravity-fed systems are channeled, in which water is diverted from a surface supply through channels onto the fields, and empoldered, generally located on low-lying coastal plains where dikes protect fields from salt intrusion. The two types of mechanically fed systems are water-lifting technologies, including calabashes, buckets and pails, tin cans of various sizes, paddles, waterwheels and shaddoufs, and water-pumping systems, which typically use diesel pumps to raise water to the fields.

2) Each of these four types of systems operates within a particular socio-ecological niche. To determine which technology to implement under given circumstances, planners and decision-makers must take the following into account:

- local ecology, hydrology and geomorphology;
- access to investment credits;
- proximity and access to urban markets;
- access to the material, services and inputs required to support the technology;
- availability of and competition for labor;
- opportunity cost of irrigated production;
- local systems of land rights;
- system of management required for effective use of technology; and

- national pricing, import/export and foreign exchange policies.

Each system is well adapted to certain combinations of these factors. At present, pumping technologies are generating the most general and widespread interest, but the three other systems also have a role to play in the expansion of low-resource irrigation in Africa.

3) The process of diffusing low-resource irrigation technology must be mediated by a continual informational exchange between beneficiaries and planners/implementers. The latter, who are from outside the local setting, have to define the significant factors that determine the sustainability of schemes in each setting. They will also have to determine the dynamic relationship among these factors. From this contextual basis, they will be able to initiate discussions with the beneficiaries regarding the scheme's design. Once initiated, this dialogue must be maintained throughout the project's life and the implementation system adjusted to evolving circumstances.

4) There are a number of constraints that are retarding more rapid expansion of low-resource agriculture in tropical Africa:

- the scarcity of investment capital;
- problems with land titling and tenure;
- national policy on the importation of production support inputs;
- poor understanding of the role of irrigation in the farming system;
- technical weaknesses, particularly in groundwater hydrology and agricultural engineering;

- local shortages of agricultural labor; and
- extension services that are poorly prepared to mobilize local groups to design, construct, operate and maintain low-resource irrigation schemes.

5) However, there has been a convergence in recent years of several factors that has created a promising environment for expansion of low-resource irrigation:

- Africans are investing heavily in it;
- the policy climate is becoming more favorable;
- production crises in many countries are motivating donors, host governments, nongovernmental organizations (NGOs) and local citizens to expand irrigation;
- the increasing priority of food self-sufficiency encourages expansion;
- the international research community has recently launched a series of research programs on it; and
- it is well suited to diffusion through NGOs.

6) Although the climate is becoming increasingly favorable for concerted programs to expand low-resource irrigation, several cautions must be kept in mind:

- above all, low-resource irrigation schemes must keep the burden of capital and recurrent costs for users down so as not to compromise the scheme;
- groundwater pumping schemes should be developed carefully;
- land rights have to evolve as conflicts over irrigation erupt;
- irrigation development strategies should minimize the burden on national institutions; and
- research programs must be justified according to their pertinence to a model of the irrigation's role in the socioeconomics of agricultural production.

7) Low-resource irrigation technologies have a great, but unquantifiable, potential for expansion. This potential is probably greatest in the Sahel and East Africa. In addition to technical bases, there are three essential preconditions for wider adoption--investment capital, a labor force and encouraging policies. The important research priorities to support more efficient performance of low-resource irrigation are farming systems studies, pumping options guidelines, groundwater hydrology and innovative technologies. It is necessary to keep in mind that innovative technologies must have low user costs or else they will defeat the purpose they are intended to serve.

8) The main point here is that low-resource irrigation technologies are well suited to the natural and socioeconomic environments found in tropical Africa. Indeed, Africans have been demonstrating the truth of this statement in the dramatic increase in low-resource irrigation schemes all over the continent in the last 10 to 15 years. The problem for donors and host governments is to develop programs and projects to encourage further expansion of this movement. The first step is a careful program of research to identify the critical elements in sustainability of these schemes. Ultimately, donor intervention must aim at minimizing the cost recovery burden on the user, as the main adaptive advantage of these schemes is their low cost to users. Perhaps the best support donors and host governments can give to widen adoption of low-cost irrigation technologies is to create a nurturing environment, while actual implementation of

schemes need not be carried out directly by donors or host governments.

II. DESCRIPTION OF THE TECHNOLOGY

9) The Food and Agriculture Organization of the United Nations (FAO) recently (1986) estimated that 5.2 million hectares are under irrigated cultivation in tropical Africa. In the Sudano-Sahelian zone, irrigation accounts for approximately seven percent of the land under cultivation. In the more humid areas of West Africa, it covers two percent of agricultural land and in East Africa, perhaps four percent. FAO classifies 2.18 million hectares (43 percent) of the continent's irrigation as traditional private operations that are, for the most part, low-resource technology irrigation.

10) At the outset, it is essential to be able to distinguish low-resource, small-scale irrigation in Africa from other irrigation activities. The cardinal features of low-resource irrigation are:

- operation and maintenance of the system is assured by user labor and inputs;
- the system is managed as an integral unit by an institution created by, composed of and led by users;
- the capital to develop and sustain the system comes, by and large, from the users;
- users generally develop the technical skills to design, construct and operate the system through a continuous iterative process;
- the cost of development and operations of the system is low and usually covered, in large part, by user labor; and
- the users alone make the decisions regarding the role irrigation will play in their agricultural production strategies and farming systems.

11) As population densities rise, low-technology, small-scale irrigation can, under the right ecological conditions, become a strategy for intensifying agricultural production which, in principle, has an advantage of low-cost and high-user autonomy. Investment to develop the systems is low, as their development is more labor- than capital-intensive. The initiative in developing and sustaining the system rests with the users. The management system, therefore, grows out of the users' social system rather than being imposed on it. Users make the decisions about the technology for the system. They make their choices based on the real irrigation experience that they and their neighbors have. Finally, the independence of the system is a big benefit. Waldstein (1984) argues that dependence of irrigation communities on a national institution impedes local users because they have to depend on the institution for technologies, inputs, cultivation services and, markets, without which they cannot benefit from the irrigated areas available to them. Yet, by their very structure, national institutions have to be more immediately responsive to the political constituencies that gave rise to them than individual client cultivators.

12) There are two basic classes of small-scale irrigation in Africa, gravity-fed irrigation and mechanically fed irrigation. For the purposes of this paper, gravity-fed irrigation includes only systems in which there is a field system requiring earth moving. This eliminates the classical flood recession systems of the major river valleys, for example, from consideration.

However, it includes two main types of gravity-fed systems. They are the channeled systems, such as the highland irrigation systems of Madagascar, Tanzania and Kenya, and the interior lowland systems of Somalia; and the polder systems of Lake Chad and the Upper Guinea coast of West Africa.

13) In the channeled systems, water is diverted into the system from a usually perennially flowing stream. In the Sonjo case in Tanzania (Gray, 1963), the system is fed by a group of springs. Thus, it is usually possible to cultivate more than one crop per year. Water is conducted from the diversionary structure to the fields by a network of greater and lesser channels. Individual fields are divided from each other and separated from the field channels by low bunds. Fields are usually flooded by breaking the bund at one point to allow water to enter. The break is closed off with mud, wattle or a sack filled with sediment at the end of watering. It is very common to use irrigation water in conjunction with rainfall, especially in areas with more than one rainy season. The system can be designed, constructed, operated and maintained purely with local labor. It has little capital cost at any point. The users themselves can meet its needs for institutional support. Generally, production is primarily for family consumption, although some share of production is destined for market. In the Lower Shabeelle Valley in Somalia, for example, Boateng et al. (1986) found that about one-third of the maize crop was marketed.

14) The poldered systems of the Upper Guinea coast are built on low-lying, swampy plains, intersected by a network of channels, which drain waters to the sea in the rainy season and conduct saltwater inland, especially at high tides, during the dry season. Users built the polders to protect their fields from salt during the dry season. They open the dikes to flood fields with fresh water as part of the process of desalinating the land. They also use river water in conjunction with rainfall to irrigate their field crops, (Linares, 1970, 1981). The polders in Lake Chad are managed differently. People create polders by trapping water by diking off a stretch of water between two islands in the lake. Water infiltrates the lake bottom and people plant in the moist, heavy clays that are left. Later, they burst the dike to flood the land again and wash out salt accumulation (Bouquet, 1974). As with the channeled systems, the polder systems are technically and institutionally within the control of the users. The cost of technology is very low, in cash terms, and must be evaluated mainly as the opportunity cost of labor. The benefits are mainly in terms of subsistence production, evaluated as the shadow value of food crops. In the minds of the producers themselves, these systems make economic sense. The systems of the Upper Guinea coast predate the earliest European explorers. The polders in Lake Chad are more than 100 years old.

15) Mechanically fed systems cover a broader array of technologies than gravity systems. The two basic technologies are water lifting and water pumping.

16) Water-lifting technologies include calabashes, buckets and pails, tin cans of various sizes, paddles, waterwheels and shaddoufs. All of these technologies depend on a relatively high water table. The limit of effectiveness for a shaddouf, for example, is about four to five meters beneath the surface. Most of these systems use human energy to lift water from a hand-dug well into the main channel of the irrigation system. As a general rule, because of the physical limits of human drawing power, one well can irrigate only a quarter to a half a hectare. The scale of operations made possible by a single well is so small that this irrigation technology makes practically no institutional demand on the users. These systems are usually operated seasonally as a supplemental food production system operated in conjunction with rain-fed agriculture or livestock herding. Most often, they operate during the dry season to produce high-value crops for market, such as vegetables. However, there are a number of small water-lifting systems in Chad that are operated perennially. In addition to the usual dry season crop of vegetables, people plant maize to germinate in a water-lifting system and mature under rainfall. The water-lifting system makes possible a second cropping season wherever it is used. Under contemporary Chadian conditions, it also effectively extends the rainy season for the food staple.

17) Of all of the technologies discussed, water-pumping systems require the greatest cash investment. Pumping makes it possible to draw relatively large quantities of water from wells or over the river levees. Pumping schemes are operated by a wide variety of user institutions. Many are owner-operated by single private entrepreneurs. Others are operated by cooperatives. Still others are village schemes. The cost of buying, operating and servicing the pump distinguishes the process of development, operation and maintenance of a pumping scheme from other low-cost technology irrigation alternatives. It forces the users to program operations in the scheme for a certain level of cash returns. Because of fuel costs, the pumps are usually operated only during the dry season when users focus on growing high-value crops for market. In fact, these schemes tend to be concentrated within convenient transport distance of large markets. These schemes are the most expensive to construct, operate and maintain. More than the other low-technology irrigation alternatives, they need the support of service institutions, such as mechanics, to stay in operation. On the other hand, they are capable of generating significant cash returns for their users.

III. STATUS OF SMALL-SCALE IRRIGATION

18) Under any circumstances, irrigation requires greater inputs of time, effort and capital than rain-fed agricultural or livestock herding systems normally practiced in tropical Africa. Users develop their own irrigation systems when two independent variables converge. The first is the local demographic picture.

19) African populations are very mobile. Movements respond to a number of political, social and ecological factors. In response to persistent drought conditions in many countries, more than anything else, movements of the past decade or so are consistent with long-term historical patterns. The long-term trend is for population densities to rise dramatically in areas with a secure resource base. As competition for scarce resources rises, pressure rises to increase the return to their use. Increasing population densities, therefore, puts pressure on people to intensify agricultural production.

20) Population movements are important as well in meeting the labor requirements of irrigation. Experience has shown that labor shortages are a major constraint holding back the development of irrigation in Africa. Irrigation is, therefore, only feasible in relatively high population-density areas where a labor supply is available.

21) Irrigation is linked to demography in a third way. Rural-urban migration leads to concentration of large numbers of people in nonfood-producing centers. People in these centers acquire their provisions through the cash/produce markets. Markets are a

critical spur for intensification of agricultural production. Market access is an important incentive to development of irrigation.

22) The second independent variable that promotes development of low-technology, small-scale irrigation is local ecology. Irrigation is possible only under certain ecological conditions. The geomorphology of Africa is different from Asia. Large-scale irrigation, such as in Asia, is feasible on vast alluvial plains. Such areas are practically nonexistent in Africa outside the Nile Valley and the interior delta of the Niger River. Therefore, irrigation is generally feasible in Africa on a much smaller scale than in Asia, in flat areas with multiseason water supplies and soils with adequate clay content.

23) Demographic and ecological factors place limitations on the development of low-resource technology irrigation in Africa. However, these two factors do converge in many places. Irrigation, if not yet realized, is a potential development in those places.

24) This section will describe each of the four low-technology irrigation alternatives introduced in Section II.

A. Channeled Irrigation

25) The main location for gravity-fed, channeled irrigation is the highlands of East Africa and Madagascar. An important exception to this generalization is the Middle and Lower Shabeelle Valley in Somalia. All of these systems depend on the

runoff from heavy rainfall in the highlands to irrigate the fields.

26) Many of these systems have been in existence since before colonial times. The Shabeelle River systems in Somalia were built during the colonial era. Several authors (Fleuret, 1985; Obara, 1984; Kimani, 1984) suggest that many of these schemes have fallen into disuse due to problems with disease, labor recruitment, migratory wage labor, land alienation, and altered systems of justice and administration.

27) In Kenya today, gravity-fed, channeled, low-resource technology irrigation covers no more than four percent, 800 to 900 hectares, of irrigated land (Kimani, 1984:262). By contrast, an estimated 82 percent, 117,000 hectares, of all irrigated land in Tanzania is of this type (Mrema, 1984:310). In Madagascar, irrigation of this type covers 70 percent of the 1,000,000 hectares under irrigation in the country (International Irrigation Management Institute, 1986:10). In Somalia, about half the land on the Middle and Lower Shabeelle is fed by gravity.

28) In all of the cases mentioned, the users are overwhelmingly dependent smallholders. In the entire highland zone where gravity-fed irrigation is practiced, it is the primary agricultural technology. Every family with any land rights in a society that uses irrigation will have rights to irrigated land. This includes the vast majority of families. These systems are

developed and maintained as community systems and virtually all member families of the community have rights in them.

29) The social organization of use and management reflects the social organization of the community, whatever its equities and inequities. The role and rights of women varies considerably from system to system. As a general rule, canal maintenance is primarily men's responsibility, although women occasionally can be seen cleaning canals and carrying dirt. Men do most of the land turning as well. The entire family shares in the planting, weeding and harvesting. Women's rights to their own plots depend on local inheritance practices, their marital status and the rights of their families into which they are born or into which they marry. Cultivation in gravity-fed systems is so labor intensive that almost all plots are worked by undifferentiated family groups, although it is very common for individual members of the family group to be allocated a small section of the plot to cultivate a crop for their exclusive use.

30) International donor attention to schemes with this technology has been limited. The European Development Fund (EDF) has been investing money in diversion structures in the systems in Madagascar over the last 20 years. Both the U.S. Agency for International Development and the World Bank are exploring projects to improve the performance of the systems along the Shabeelle in Somalia. The government of Malawi has had a program of technical assistance to so-called self-help irrigation schemes since the last 1960s. Other than these cases, there has been

relatively little donor interest in gravity-fed channeled systems. If anything, the importance of these systems has been declining in recent years.

31) This technology fails to excite more interest for several reasons. The main reason is probably that, while the investment in the system is small, the returns to investment are also low. These systems do not include any storage. Water is usually available seasonally as a function of rainfall in the watershed. Hence, these gravity-fed systems are for supplemental irrigation, as opposed to full-control systems. Runoff is being used, in effect, to stretch the rainy season and reduce the risks of rain-fed agriculture. The Lower Shabeelle case is typical. There are two rainy seasons in the area, and people cultivate in each one. They flood the fields and plant just before the rains. Crops germinate under irrigation, but mature under rainfall. In dry years, they may irrigate a second and third time during the season if there is water in the canals. In a particularly rainy year, they do not irrigate even at the beginning of the season.

32) A second reason this technology is not attracting real interest at present has to do with geography. Gravity-fed systems flourish only in highlands areas. They depend on steep inclines to feed their systems and channel away their drainage. Economies all over Africa are becoming increasingly market driven. As mentioned, this is especially true for irrigation where the investment is worthwhile only if people are able to produce surpluses and have access to markets for them. But the

topographical conditions that foster gravity-fed systems are independent of the requirements of market access. The Shabeelle systems are an exception that proves the rule. They are not in highlands areas and are seriously troubled with drainage problems. However, the most distant is located about two and a half hours down a paved road from Mogadishu, the main consumption center in the country.

33) Other major constraints in the system include shortcomings in the engineering of the systems, such as inefficiency of water conveyance and water use. Water infiltration through the banks of channels is high due to poor compaction.

34) In summary, channeled gravity-fed systems are very low-cost systems to develop, operate and maintain. They are generally used as supplementary irrigation systems to mitigate the risks of rain-fed agriculture. This technology is viable only under particular ecological conditions. Interest in extending them has lagged, except for certain special cases, because the return to an investment in developing or improving the performance of these systems is less attractive than for other low-resource technology alternatives.

B. Empoldered Irrigation

36) The main location for gravity-fed empoldered irrigation is in the lowlands of the upper Guinea coast. in addition, people have developed a number of polders in the southeastern portions of Lake Chad. In channeled systems, the channels are used to bring water into the fields, while in empoldered systems, the

polders protect the fields from excess water. All empoldered systems have been built in areas with excess water. Moreover, in upper Guinea coast systems, the threat is from saltwater intrusion during the dry season.

37) As is true of the channeled systems, most of the empoldered systems have been in existence since before the colonial era. The Lake Chad systems date mostly from the early years of colonial occupation, although the polder technology used there was first perfected during the third quarter of the 19th century. However, the Lake Chad polders have fallen out of production in recent years. A succession of drought years has caused a dramatic recession of the lake's shores. In July 1985, the empoldered areas were many kilometers from the water's edge. Many polders in Guinea-Bissau have dropped out of production. They were destroyed in the course of the war of independence which ended in 1974.

38) Among the Diola of the Basse Casamance Department of Senegal, irrigated rice cultivation in polders is the most important food production activity. The same is true for the Balanta and Manjaku of Guinea-Bissau and the Baga of Guinea. In each case, irrigation dominates the agricultural landscape. The aggregate population of irrigated cultivators on the upper Guinea coast is from 700,000 to 900,000. The polders in Lake Chad cover a much smaller area. Not everyone in the neighborhood of the polders has cultivation rights, and the polders represent only

one food production resources and compete primarily with livestock herding and dryland agriculture for labor.

39) In the case of the polders of the upper Guinea coast, the vast majority of users are smallholders. As with channeled irrigation, every family with any land rights in a community will have rights to irrigated land, which includes most families. The societies of the upper Guinea coast are essentially egalitarian. However, the Lake Chad polders are in an area of hierarchical societies. Labor in these polders has been provided disproportionately, either on their own freeholds or as clients of clan chiefs or sultans, by the lower levels of society. Interest in working the polders has been in inverse proportion to a family's wealth in cattle.

40) Linares (1985) estimates that men and women in the Diola villages she studied work equally hard in the rice fields and perform complementary tasks. Each hectare takes about 105 days labor for a women and 108 for a man. Men's work is concentrated on preparing the nursery and ridging the rice paddies. The women work on transplanting and harvesting. She goes on to state that:

> Young men at the time of marriage receive rice fields from their father . . . and immediately transfer some parcels to their wife. . . . Agnatic women have no rights of disposition over paddy land, but their usufructory right in their in-married context are inviolable. . . . Thus, in-married women have ultimate security as land users, if not landowners, in the rice paddy system. (1985, p. 88)

This system of labor and access rights for Diola women is typical of practices prevailing on the upper Guinea coast.

41) International donors and host governments have been very interested in improving polder performance. In Senegal, there has been a series of irrigation project in the Casamance since the 1960s. AID financed an irrigation project that focused on improving their performance and ended in 1984. Its most noteworthy predecessor dates from the early 1970s and was financed by the People's Republic of China. It used a labor-intensive-production strategy based on the local system. In Guinea-Bissau, AID and other donors have been working on reconstruction of the polders for the past seven years. In Chad, both AID and the World Bank had polder development projects they had just started when they were forced to withdraw because of civil unrest in the area in 1981. After a series of studies upon their return, they both concluded that recession of the lake rendered further polder development problematic.

42) The main problem encountered by the coastal systems is their dependence on rainfall for more than simply watering their crops directly. If the rains are sufficient, salty water will be pushed downstream during the rainy season, but if insufficient, salts accumulate in the rice fields with disastrous consequences for productivity. In Lake Chad, a drop in rainfall also cripples polder production. As along the coast, rainfall from the entire watershed is channeled toward the polders. When rainfall drops too much throughout the catchment, the lake level does not rise enough to flood the polders.

43) Another problem is that polder technology is used mainly for subsistence production, but production is on a large enough scale to produce substantial surpluses for market. Moreover, since the polders are virtually surrounded by water, these areas have relatively easy access to markets. However, each individual family produces only small surpluses, and their cash income from irrigation is small. For example, the main cash income in Basse Casamance in Senegal comes from peanuts cultivated on high ground outside the polders. Thus, people have very little cash that they are willing to invest in improving polder performance.

44) In summary, empoldered gravity-fed systems, just as channeled gravity-fed systems, are very low-cost systems to develop, operate and maintain. Polder technology is viable only in a few very particular ecological zones in Africa. These places are generally well watered, featureless lowlands with low gradients and rich soils that are very productive agriculturally. Thanks to this productivity and generally convenient access to markets, often via water transportation, there has been fair interest among donors and host governments in improving the performance of existing systems. On the other hand, because of their particular ecological requirements, extension of these systems is only a limited possibility.

C. Water-Lifting Systems

45) Irrigation technologies that rely on human or animal power to feed water into the system are scattered all over Africa. As with the other two low-cost technology irrigation systems already

discussed, water-lifting technologies are viable only under particular ecological conditions. However, these systems are concentrated in low-lying areas where the water table is relatively close the surface. These systems are especially concentrated across the Sahel from Senegal to Sudan. The most common location is in depressions between either live or fossil dunes in all of these countries. In addition, there are a number of systems in northern Togo, northern Ghana and throughout Burkina Faso which are fed from village barrages that store rainwater runoff. There are several different ways of getting water onto plots from the barrages. These systems are relatively scarce in eastern and southern Africa where the water table is deeper, and soils rockier and more difficult to penetrate.

46) Most of the water-lifting systems in Africa are relatively recent, with the exception of the Niayes area in Senegal, which has been producing vegetables for the urban markets of the Cape Vert peninsula for two generations, the systems of the Air Mountains and numerous oasis systems. Otherwise, water-lifting systems have been developing rapidly in the Sahel since the onset of the series of drought years that began in the late 1960s. Systems in southern Mauritania date from the mid-1970s, and use of the shaddouf in the Lake Chad basin dates from the same period. These recent systems are being used by small, scattered groups. Water-lifting systems are growing dramatically as people find other economic opportunities closed off. Many had large livestock resources that they have lost. In Chad, communities of

herders from the north and east came to the shores of Lake Chad to practice shaddouf cultivation when they lost their herds. In northern Burkina Faso and southern Mali, people are using water-lifting technologies to introduce a new staple (potatoes) into the diet to compensate for the drop in millet and sorghum production caused by the dry conditions of recent years.

47) Each of these water-lifting systems is very small--human or animal power can lift only so much water in a day. In addition, each well has a limited capacity, so there are usually several wells at any one location. The users of each well are virtually independent of those using wells at the same site, so one site fed by water-lifting technologies is actually a cluster of autonomous systems. With the exception of the Niayes and some systems in Niger, the rural farm families using these systems tend to be less well-off. Families that are better-off have either the resources to invest in pumping or managed to preserve their livestock.

48) To date, these systems have not attracted much donor interest. In December 1986, AID will be launching a study of irrigation in Chad to identify strategies for supporting and extending water-lifting, among other technologies. In addition, the Niayes and some systems in the Dallols and Niger's Maggia Valley have received donor support, as they had the greatest commercial possibilities. Most outside support for water-lifting systems has come from NGOs--Africare has been active in northern Burkina Faso and CARE in Chad's inter-dunal depressions. Again,

these are systems with commercial orientations, but the scale is small enough to fit well with NGO capabilities.

49) The biggest issue raised by this technology is the level of commitment among users. The dramatic surge in the development of water-lifting systems in recent years is a response to ecological conditions that may or may not persist. If water-lifting irrigation technology is just a stopgap measure, the prognosis for projects using it would not be hopeful after three or four good rainy seasons. On the other hand, this is a low-cost technology that people use mainly in the off-season to produce a small crop. If there is a market for off-season production, people try to expand their operations by investing in pumping. In that case, water-lifting technology may simply represent a first step in a progress to long-term intensification of food production. Still, commitment to the technology remains an open question.

50) The operation of water-lifting technology is often dependent on groundwater, but groundwater hydrology is unknown for almost all of Africa. Salinity levels and recharge rates are important determinants of the potential intensity and longevity of water lifting. Another potential constraint on extension of this technology is land tenure and competition for resources. Those with plots irrigated by water-lifting technologies are a minority of local residents. They are interested in establishing long-term exclusive rights to irrigated plots. At some point, this will create tensions with others who have not yet staked their

claims, for whatever reasons. In northern Burkina Faso, water-lifting irrigators exercise their rights to land on the barrage only during the off-season when rainy-season land users are willing to forego their claims.

51) In sum, this is also a low-cost technology that is viable with only local expertise and materials. It is practiced on small plots in areas with a high water table where hand-dug wells are feasible. Recently, in response to a drop in rainfall, water-lifting systems have proliferated over large areas of the Sahel, in particular. Donor interest in these systems has been only fair because:

- they are localized and often isolated;
- production is subsistence, rather than market, oriented in many areas;
- the technology's irrigation capacity severely limits the possible level of agricultural production; and
- people are probably inclined to return to less intensive technologies or upgrade to water-pumping systems, instead of remaining committed to water-lifting technology.

In cases with nearby markets for goods, water-lifting technologies can be very profitable due to their low costs for construction, operation and maintenance. They deserve serious consideration by donors, host governments and NGOs.

D. Water Pumping

52) Water pumping using small diesel engines to power pumps is the most widespread and rapidly expanding low-resource technology used in African irrigation with sites scattered all over the

continent. Their presence is a function of three factors--availability of water and the initial cash investment, and access to lucrative markets. Technologically, there are two major types of pumping schemes, surface water and groundwater.

53) Surface-water pumping schemes are most common along Africa's great rivers. Diemer and van der Laan (1983) estimated that in 1982, there were over 400 such schemes along the Senegal River--250 in Senegal, 150 in Mauritania and 17 in Mali. They are present all along the Niger River, but especially in the vicinity of the urban centers, such as Bamado, Gao and Niamey. There has been a great surge in the development of pumping schemes in the last 15 years all over northern Nigeria. These schemes draw water from the Niger, Benue and tributaries of Lake Chad. In Chad, a number of pumping schemes have sprung up along the Chari River since the end of civil unrest. In Kenya, such schemes are concentrated on the Tana River, and in Somalia, on the Shabeelle. In Zimbabwe, there 67 schemes in communal areas along a number of major and minor watercourses, and in Zambia, along the Kafue and Zambezi. People also pump water from lakes and holding ponds, or practice water harvesting. Generally, the need for pumping is a function of the seasonality of African rainfall and the rivers' flood and recession cycles. Over millenia, these factors have established high levees along minor channels. Thus, schemes most commonly occupy the levee and pumping is necessary to bring water from the river up the levee into the fields.

54) Groundwater pumping schemes can require a much greater initial investment. Many involve simply using a small pump as a substitute for human or animal power in water-lifting schemes. Others are fed by boreholes that can be 100 to 150 meters or more deep. In Senegal's Ferlo desert, there is a lot of cultivation using water from boreholes, but they were drilled for livestock, not cultivation. Botswana is currently discussing the development of a network of boreholes for irrigation, but it is better-off than most African countries and irrigation from boreholes is not very common in Africa. The issue might also be raised whether it is actually a low-resource technology.

55) In a recent personal communication, the director of Niger's national irrigation agency (ONAHA) estimated that there are approximately 700 pumping schemes in that country alone. The International Irrigation Management Institute (IIMI, 1986) estimates that private pumping schemes in Sudan cover 134,000 hectares. In general, these schemes are so dispersed and often so isolated it has been impossible to count, let alone survey, them. There are surely thousands of pumping schemes throughout tropical Africa. Diesel pumping is the most rapidly expanding low-resource irrigation technology. New schemes spring up every dry season, while others drop out of production for a number of reasons. Typically, the people benefiting from pumping schemes represent only a minority of the local population because of the rigorous requirements for mounting a pumping scheme. However, in some cases, whole villages are involved.

56) There is an even greater range of management systems for pumping schemes than technologies. A large number are individually owned and managed. The owners are often merchants, migrant laborers returning from jobs outside the country or civil servants who acquire the capital to mount the schemes from their full-time occupation that generates cash. They locate near urban centers and use local labor to grow annual crops for market, mainly those with high value, such as vegetables. However, the majority of pumping schemes are owner-operated by groups organized on a wide range of principles. Groups can be made up of entire villages; sections of villages; clans, lineages or families; or occupational groups. They may also be organized by sex, such as women's groups, age or even as the local chapter of the national political party. Village groups often use pumping schemes for susbsistence crop cultivation. More focused groups usual concentrate on growing high-value crops in the off-season for market. Group members retain their shares of the receipts to use for their own purposes. Under whatever management system, the pumping technology is open to everyone, except those with no local social and political ties, usually only the most recent migrants in the area.

57) Water-pumping technology has been generating wide and growing interest among international donors, host governments and NGOs. The World Bank has been involved in promoting pumping schemes in Nigeria. A German NGO has been doing a study on rehabilitation of communal pumping schemes in Zimbabwe, which the

World Bank may follow up on with rehabilitation credits. The bank financed a group of village pumping schemes in Chad that continued to produce through years of civil unrest left entirely to their own devices. The Malawi government has been giving technical assistance to so-called "self-help" pumping schemes. AID is financing a study of irrigation in Chad that will examine pumping schemes under several management systems. The Club du Sahel, with French, Dutch and American funding, is mounting an update of irrigation studies that it conducted in the Sahel in the late 1970s. This update will introduce a treatment of "spontaneous" irrigation, which is the proliferation of pumping schemes for the most part. In 1984, Underhill launched FAO consideration of low-resource technology irrigation with a widely read paper. Since then, low-resource technologies, principally pumping, have been playing an increasing role in FAO discussions and technical assistance programs. The European Development Fund is organizing a dozen village pumping schemes on Chad's Chari River. The Dutch government has been undertaking similar efforts in Senegal, and the German government is involved with a group of pumping schemes in Somalia. NGOs have village pumping projects in practically every African nation. In brief, water-pumping technologies are currently attracting the broadest possible interest from all parties concerned with irrigation, both within and outside Africa.

58) Of all low-resource irrigation technologies, pumping schemes have the highest costs for development, operation and

maintenance. They are also the most dependent on outside institutions to furnish spare parts, fuel and maintenance services for the pumps and to channel agricultural inputs into the schemes, which is a virtual necessity to raise production levels to the point where costs can be met. While pumping schemes are the most productive low-resource irrigation technologies, they are also the most vulnerable because of their dependence on outside institutions.

59) Engineering is a major shortcoming with many of the pumping schemes developed privately and by NGOs. The canal layout of many schemes is not well planned, and consequently, they distribute water inefficiently. In addition, there is a wide range of pumping options to choose from. Developers of pumping schemes, whether they are private individuals, village groups, NGOs or government agencies, have found it difficult to identify the pumping technology that is best suited to each scheme's social, institutional and ecological circumstances.

60) In summary, water-pumping technologies for irrigation are attracting enormous attention in tropical Africa. Their use has grown dramatically in the last decade or so. These schemes require a large initial investment and carry a high recurrent cost burden, compared to other low-resource irrigation technologies. However, they are often very productive. Thus, they have to focus on market production. For these and other reasons, donors, host governments and NGOs are becoming

increasingly involved in improving and extending water-pumping irrigation systems.

IV. APPLICATION OF OTA PRINCIPLES AND CONCEPTS

61) At the end of this section, a table is provided to illustrate the application of principles and concepts that OTA has developed for managing natural, human and institutional resources for low-resource agriculture to irrigation technologies.

62) There are essentially two classes of tasks to be done to effectively promote the expansion of low-resource irrigation technology. The first class involves building the knowledge and understanding of donors and host-government professionals. Enough is generally known about low-resource technology irrigation in Africa to recognize the importance of OTA's principles and concepts in implementation. Low-resource irrigation plays a particular role in its practitioners' overall farming system. However, at specific project sites, information about the role that low-resource irrigation is playing the farming system is needed. Thus, it is important to have some sort of farming system study of an irrigation community before proceeding with development programs. The farming systems study internalizes the systems orientation that is fundamental to OTA's approach. A farming study, that is properly executed by researchers from international agricultural or national research centers or universities, will contribute insights into several other OTA principles and concepts. It will catalog local resources, give a socioeconomic profile of beneficiaries, evaluate their strategies for irrigation production in terms of

risk aversion and long-term sustainability of production. A major problem in conducting farming systems studies in Africa is that the farming system perspective has not yet achieved general acceptance in African research institutions. Part of the reason for this is, of course, that no general agreement exists among researchers worldwide about what constitutes a farming systems study. Thus, the farming systems research that is needed will have to be designed, case by case, to fit the specific context, which is probably for the best.

63) The second class of tasks is centered on those that institutionalize findings from the systems studies in programs, projects and other activities. The target group in this case is the planning and implementation staff of international donors, host-country governments and contractors. This is such a diffuse group that the process of institutionalization will be long and difficult. In terms of enhancing external linkages, it will require substantial investments. In most areas, it will also require continual training, which also demands a substantial investment.

64) In principle, low-resource irrigation technology seems to be more compatible with women's interests than more capital-intensive technologies. Women generally play their most important roles in the production of crops for family consumption, as opposed to those for cash sale. Many low-resource technology irrigation schemes focus on subsistence production. Exceptions to this rule are often private vegetable

producers that are near major markets. Many are production systems designed to supplement the family's primary food production activity. Here the exceptions are found mainly along the upper Guinea coast or in highland Madagascar. Even in these cases, women supply a large portion of the field labor. They often have plots in the system whose product they alone control and have an important voice in the disposition of production from family plots as well. However, the role of women in low-resource irrigation varies considerably across schemes. A recent WARDA/University of Wageningen study (1986) in the upper Senegal valley has shown that women supply most of the field labor in certain villages and men do in others in the same zone. The differences are closely tied to the historical development of the social groupings in the villages. In general, women's participation will best be preserved by promoting schemes for seasonal production of crops designed to supplement the family's main production activities. In fact, this strategy is consistent with the scale of the technology.

Application of OTA Principles and Concepts to Irrigation Technologies

What needs to be done	How to do it	Who does it	What limits it
Principle A - Implement Systems Approach:			
- determine systematic relations among elements in irrigation systems	- use secondary literature - conduct farming systems studies - conduct rapid reconnaissance surveys	- IARCs, national research centers and universities	- lack of funds - shortage of staff with farming systems research training
Principle B - Enhance Positive External Linkages:			
- improve transmission of market signals to irrigation systems	- collect and broadcast data daily	- national agency	- lack of funds - lack of staff
- develop and maintain transportation infrastructure	- send out well-equipped repair crews	- national agency	- lack of funds - lack of staff
- develop and maintain rural credit institutions	- develop credit institutions able to lend to smallholders	- national or private institution	- lack of funds - problem to assure loan repayment
- develop and maintain access to material, technical support and production inputs	- promote private-sector expansion into these sectors	- national or private institution	- lack of funds - inadequate policies
- develop congenial policy environment	- conduct policy analysis	- national research centers	- lack of funds - muddled priorities
- identify specific strategies for minimizing risk	- conduct farming systems studies - use secondary literature - conduct rapid reconnaissance surveys	- IARCs, national research centers and universities	- lack of funds - few staff with FSR training
- implement measures to help farmers manage risk	- determine steps based on research	- national agencies	- lack of clear policy directions

What needs to be done	How to do it	Who does it	What limits it
Principle D - Use Local Resources:			
- determine local socioecological context for irrigation	- conduct farming systems studies - use secondary literature - conduct rapid reconnaissance surveys	- IARCs, national research centers and universities	- lack of funds - few staff with FSR training
- develop strategies for coordinating policies, programs and projects with local resource performance	- ensure farmer participation in planning and implementation	- planning and implementing agencies and contractors	- lack of funds - inadequate systems for integrating local input in process
Principle E - Accommodate Heterogeneity of Beneficiaries:			
- analyze proposals for their implications for socioeconomic interests of range of beneficiaries	- conduct farming systems studies - use secondary literature - conduct rapid reconnaissance	- IARCs, national research centers and universities	- lack of funds - few staff with FSR training
- make consideration of range of beneficiary interests an integral part of development process	- ensure range of beneficiary participation in planning and implementation	- planning and implementing agencies and contractors	- lack of funds - inadequate systems for integrating local input in process
Principle F - Determine Effects by Gender:			
- determine roles under irrigation technology as assigned by gender	- conduct farming systems studies - use secondary literature - conduct rapid reconnaissance surveys	- IARCs, national research centers and universities	- lack of funds - few women in agricultural research and extension
- increase role of women in agricultural research, training and extension	- increase training of women	-IARCs, national research centers and universities	- lack of funds - insufficient employment opportunity after training

What needs to be done	How to do it	Who does it	What limits it
Principle G - Maintain Systems for Sustainability:			
- identify conflicting long- and short-term interests that lead to mining resources	- conduct case studies - use secondary literature - conduct rapid reconnaissance surveys	- IARCs, national research centers and universities	- lack of funds - inadequate conceptual models for task
- design and implement systems where long- and short-term interests coincide enough for sustainability	- apply results of studies to identify conflicting interests	- planning and implementing agencies and contractors	- lack of funds - lack of pertinent study results
Principle H - Promote Local Participation:			
- bring farmers into all important design and implementation decisions	- develop agendas and conduct farmer consultation	- planning and implementing agencies and contractors	- lack of funds - inadequate conceptual models for task

V. KEY POLICY ISSUES

A. Constraints

65) The most important factor limiting the use of low-resource irrigation is the scarcity of investment capital. In particular, a number of private individuals and groups are poised to initiate pumping schemes, but they are having problems raising money. One way of releasing this constraint would be through project assistance in the form of agricultural credit programs. Such programs would have a higher probability of success than more conventional credit programs since a precondition to launching even low-resource irrigation is long-term tenure for the plot and a certain investment in improving the land. It also presupposes some amount of cash income from cultivation. Thus, the credit recipient will have the cash to reimburse the credits, and the bank will have a fungible resource to foreclose on if the credits are not repaid.

66) Problems with land titling and tenure can be another constraint limiting the growth of low-resource irrigation. There are as many tenure regimes in Africa as there are countries. However, in general, African governments have passed a series of land laws over the last 10 to 15 years, which as in the United States, give the government title to all lands not titled to private parties. As here, the governments consider the land they hold as part of the national endowment and resist releasing it to private tenure. Unlike the United States, only a very small share of the land in any African country is privately titled, and

most of that is in urban areas. African land law usually accommodates low-intensity agriculture by giving usufruct rights to farmers on their land while they cultivate it. Under normal shifting cultivation practices in Africa, farmers invest little in improving the land they cultivate and move on to other plots after a few years.

67) Irrigated cultivation represents a major departure from shifting cultivation practices that requires an accommodation in the land-tenure regime. Land susceptible to development for low-resource irrigation is a scarce resource. Groups and private individuals are willing to make the investment in labor and cash to develop irrigation only with the assurance that they will have security of tenure on the irrigated land for the foreseeable future. Nearby villages and groups of local residents have less of a problem than private parties from outside the local area in establishing secure tenure over irrigable plots. National governments generally support the preeminence of local usufruct rights to land against any outside challenge. To establish individuals or groups from outside the local area on irrigable plots, the government has to accept the idea of the development of rural land markets. In Chad at present, along the Chari River in the vicinity of Ndjamena, local prefects are responsible to register the allocation of irrigable plots to private parties. The government will have to accept that these plots have value and gradually a lively market will evolve in those certificates of registration. Similarly, in Somalia, the government has

created a mechanism for registering irrigated landholdings. Although illegal, a market in these certificates has already arisen. Many African governments will need help thinking through a policy on land tenure that does not threaten the time-honored shifting cultivation practices of the majority of rural farmers, while protecting the security of the investments of small-scale irrigators on their plots.

68) A third major constraint limiting low-resource irrigation is national import policy. As already noted, irrigation pumping is the most rapidly expanding sector of low-resource irrigation in Africa. Thus, the feasibility and viability of any pumping scheme depend on the cost and availability of pumps, spare parts and fuel, which are almost always brought in from overseas. In addition, pumping schemes are usually market-oriented. They must be to recover the initial capital investment and recurrent operation costs. So, many pumping schemes cultivate with machine services, buy selected seed and use commercial fertilizer. Some also use fungicides and pesticides. All of these inputs have a cash cost. Many have to be imported or supported by imports. Yet, many African governments derive a large share of their revenues from import taxes. These can drive up the cost of irrigated production and discourage the extension of low-resource irrigation technology or encourage the establishment of a parallel market in irrigation paraphernalia, as in Chad. Many governments are now concluding that it is counterproductive to heavily tax imports that support food production. However, many

still need support in analyzing their tax policy for its effects on the extension of low-resource irrigation.

69) The table in the preceding section (IV) highlights a fourth constraint, weaknesses in knowledge or understanding of the role of low-resource irrigation in local farming systems. A farm family has a particular group of resources at its disposal at any one time. In essence, these resources consist of traditional production factors--land, labor and capital--and sociopolitical networks. These networks build some flexibility into a family resource inventory that otherwise appears to be rigidly limited. Low-resource technology irrigation in Africa is usually only one of several possible economic activities of a farm family. Such a family uses the particular resource mix at its disposal to pursue its economic strategy, which will be to maximize its security, while at the same time, minimizing its risks and uncertainties. The decision-making unit for the farm family bases the implementation of the strategy on constantly updated information on the value and best use of each resource at its disposal, risks and uncertainties, and trade-offs with other resources. An understanding of available resource the strategy for utilizing them is a precondition for effective support from outside institutions.

70) In-depth case studies of farming systems for communities practicing low-resource irrigation are necessary for general understanding. Rapid reconnaissance studies of target communities are needed before designing projects in particular

areas. AID will be implementing studies of this nature in Chad in late 1986/early 1987. The University of Wageningen recently completed a study, financed by WARDA, in the middle Senegal Valley that focused more on irrigation management than farming systems issues. IIMI is making low-resource irrigation systems one of the three foci of its African program. However, its research will also concentrate primarily on the management of irrigation systems and only tangentially at the role of irrigation in the overall farming system. In short, relatively little research has been or is being undertaken to establish the role of irrigation in the farming system. This issue is more important in Africa than Asia because in Africa and particularly communities that practice low-resource irrigation, this is not the only or even the most important family economic activity.

71) There are also a set of technical constraints to expansion of low-resource irrigation. The first is a lack of knowledge about groundwater hydrology throughout Africa. The depth, quality, and recharge and discharge rates for groundwater resources need considerably more research before large-scale efforts are made to expand groundwater pumping schemes. A second such constraint is the weakness of agricultural engineering expertise in most African countries. This makes laying out efficient irrigation systems difficult for villages, small groups and private individuals.

72) Low-resource irrigation keeps the costs of production under control by using labor-intensive production strategies. Local

labor shortages are a major constraint on rain-fed agriculture in tropical Africa. The problem of labor shortages is all the more acute for irrigation schemes. There are many ways of solving the labor problem. Many require a certain amount of relocation of families, which creates a host of further problems.

73) These deficiencies in technical expertise lead to a final constraint--the state of extension services in Africa. In general, extension personnel have not been trained to see low-resource irrigation as a system with complex relations to other aspects of socioeconomic life. Extension staff often have narrower technical backgrounds and do not have great skills in community organization and mobilization. Yet, in principle, extension services would be the key link between planners and beneficiaries.

B. Opportunities

74) The major opportunity in low-resource irrigation is to build on the commitment of the rapidly increasing number of Africans, individually and in groups, to invest in operating schemes using this technology. In general, donor agencies and host governments should be more alert to local assessment of the investment climate, i.e., where local investors place capital for short-term earnings and long-term growth. The answer is a wide range of animal husbandry schemes, housing construction, commercial ventures and low-resource irrigation, mainly in the form of pumping schemes. People all over Africa are implicitly bringing the information and insights of their lifetimes to bear on

evaluating the viability of low-resource irrigation and concluding that under certain circumstances, it is one of the most promising investment opportunities available.

75) Developments in the past several years have increased the attractiveness of investment in low-resource irrigation. The most important single change has been the general liberalization of food marketing policy in Africa. Until recently, staple food commodity prices have been controlled by the central government in most African countries. Price controls may have been one factor contributing to the use of pumping schemes mainly for the production of perishables, whose prices have not been controlled.

76) The strains that the recent series of drought years have placed on the food production system of many African countries have also motivated donors, host governments and local people to refocus their agricultural development strategies. Many countries are strengthening their commitment to self-reliance in food production as a way of staving off the worst hardships of future dry years. However, the objective cannot simply be national self-sufficiency. It must be at least regional self-reliance within a country. Experience has shown that it is much less difficult to bring relief supplies to national centers than rural areas.

77) Low-resource irrigation supports policies of food self-sufficiency. By its very nature, food production under most low-resource irrigation technologies is decentralized. These are relatively small systems that cost little to install, operate and

maintain. Many pumping and water-lifting schemes are scattered around throughout rural areas, operating very independently. In effect, each scheme represents a fairly reliable node of food production in an otherwise vulnerable area.

78) Another opportunity for the spread of low-resource irrigation technology is increasing interest among the international research community. As noted above, IIMI shows the most systematic interest at present. It is an institution like CGIAR, funded mainly by AID, the Ford Foundation, different European donors and World Bank. Other research institutes, such as the University of Wageningen and Hydraulics Research Laboratory in the United Kingdom, have also recently begun research programs on African irrigation that are largely concerned with low-resource technologies. In addition, as already mentioned, the Club du Sahel is launching a study to update its research of almost a decade ago on irrigation in the Sahel, which will treat low-resource irrigation for the first time. Low-resource irrigation has caught the attention of the international research community, and a number of institutions are developing important research agendas. In all cases, completion of their agendas will be a function of funding levels.

79) The final opportunity for the spread of low-resource irrigation technology is the current and potential role of NGOs in its diffusion. Thanks to the limited scale, management requirements and level of technology involved, village irrigation schemes are perfectly tailored to the capacity of international

and host-country NGOs. For example, in Chad alone, Africare, CARE, Volunteers in Technical Assistance, the Seventh Day Adventist Church, SECADEV (a Catholic NGO) and a Swiss NGO have active low-resource irrigation projects, and ORT is designing one. This situation is representative of many African countries. The point is that NGOs are interested and suited to designing and implementing low-resource irrigation projects with a certain amount of technical and community development support from outside.

C. Cautions

80) Promotion of further development of low-resource irrigation technologies in Africa requires a certain caution. From a technical standpoint, there is insufficient knowledge of groundwater hydrology and surface water resources. Project success will be a function of the availability and quality of water supplies. The French Office de Recherches Scientifiques et Techniques d'Outre Mer (ORSTOM) carried out a series of excellent hydrological studies in the Chad portion of the Lake Chad basin in the late 1960s and early 70s. The U.S. Coastal and Geodetic Survey performed similar research in the mid-1960s in the Nigerian part of the basin. Otherwise, good hydrological data are hard to find in tropical Africa. Until more information is available on those water supplies, extension of low-resource irrigation should be pursued cautiously.

81) A second point to keep in mind is that a hallmark of low-resource irrigation is intense use of local labor in its design,

construction, operation and maintenance. Donor and host-government support must not tamper with the conditions that have made this system adaptive. Thus, projects to support low-resource irrigation will have to concentrate on human resource development, rather than capital, projects, and training an effective extension service will have to take precedence over construction of civil works. The objective must be to keep the costs of system development, operation and maintenance low enough so that users to retain the independence and flexibility which give low-resource irrigation such an important role in many farming systems.

82) The point about keeping costs down deserves special attention. At present, users are paying both capital and recurrent costs. People have shown a willingness to intensify agricultural production to cover the costs of low-resource irrigation technologies, including the most expensive, diesel pumping. Intensification has its advantages, but also makes farmers more vulnerable to the vagaries of macroeconomic factors than under shifting cultivation, for example. Specifically, it means that even in low-resource irrigation systems, users are forced to employ selected seeds, fertilizers, day labor and other inputs that require cash payments. Thus, restrictions on imports, deterioration of the transportation infrastructure and competition in the labor market can all be a drag on production and thereby, on the benefits from low-resource irrigation technology.

83) Another cautionary note is to be alert to the competition for resources that may develop with extensions of low-resource irrigation. Even under the best of conditions, low-resource irrigation will be possible only at particular sites that represent a relatively small portion of the cultivable land in tropical Africa. One measure of the successful development of this technology will be the pressures, tensions and competition that developed around these sites for access to land. Host governments will have to work out some kind of accommodation in the local land-tenure regime to safeguard the schemes' productivity. This is already underway in many locations.

84) The development of low-resource irrigation may tax the management capacity of national-level institutions beyond their ability to coordinate rapid development at a number of sites simultaneously. The key is to determine a strategy for low-resource irrigation development that minimizes the strain it places on national-level institutions. One advantage of heavy reliance on NGOs is that such an organization, along with the users involved at a particular site, take the bulk of the responsibility for design, construction, operation and maintenance of the scheme.

85) A final caution relates to research programs in low-technology irrigation in Africa. There is no natural limit to interesting research programs funded by donors and host governments. Funding agencies need to begin with a general model of the social, technical and managerial operating parameters of

particular low-resource irrigation technologies. They have to begin by hypothesizing the systematic relations among parts of that model. Only in the context of those systematic relations ought they to propose research programs which are disembodied from their context.

VI. POTENTIAL OF THE TECHNOLOGY

A. General Potential

86) It is difficult to quantify the potential for expansion of low-resource irrigation technologies in tropical Africa. However, one of the main themes in this report has been the emergence of agreement among research organizations, donors, host governments and users that these technologies have great potential at certain sites under given conditions.

87) One problem in estimating the potential for expansion of low-resource irrigation is the lack of accurate data on the number of schemes currently in existence in each country and the changes in these figures that have occurred over the past two, five and 10 years or more. The problem is that national and international institutions are only now beginning to recognize the macroeconomic implications of low-resource irrigation technology. These technologies have hitherto been virtually ignored by the statistical and planning arms of most African governments despite the support they often receive from the extension service. In fact, one important contribution to understanding the low-resource irrigation phenomenon would be a series of sampling surveys to develop the baseline data for tracking the evolution of these technologies and estimate their potential with some confidence.

88) For the present, the potential for expansion of low-resource irrigation can only be qualified in orders of magnitude. The

potential is highest under conditions where the issues identified in Section V can be resolved.

B. Specific Potential

89) The Senegal river valley appears to be one place where the potential for expansion of low-resource irrigation is very great. The two most important issues--lack of investment capital and labor shortages--are resolved in the Senegal Valley by the relatively high population densities there. Labor has been underemployed there for years and has been leaving for urban Senegal and even France. These migrants have been the source of capital to develop a number of diesel pumping schemes, as many have returned to produce rice and perishables. One unresolved question is the extent to which underemployed labor is assigned to irrigation, as opposed to emigrating for Dakar or France. Meanwhile, the remittances have also fueled a market for perishable in the valley that has indirectly financed development of other schemes.

90) There were very few low-resource irrigation schemes on the Senegalese bank of the river when the national government extended the sway of the irrigation para-statal organization in 1974 to incorporate village pumping schemes. Several years of conflict ensued because the para-statal agency found it difficult to accommodate local farming systems considerations in its program. The problem was resolved with a change in the mandate of the para-statal organization in 1983. The number of pumping schemes in the Senegal Valley has grown rapidly since 1974. A

number of NGOs and donors, including AID, have projects underway to promote future growth.

91) Moris et al. (1983) have attempted to make specific estimates of irrigation potential for several other Sahelian countries. At present, they estimate that there are 157,000 hectares of irrigated land in Mali. "There are few, if any, communally managed irrigation systems in Mali. Most small-scale, traditional systems are individually manager," (p. 35). Thus, almost all of the 69 irrigation schemes identified in Mali are managed by central government institutions. The question is whether this means that there is a potential role for support to the Malian government to devolve control of its smaller schemes to local entities. The government has certainly shown an interest in devolution and privatization in recent years. Moris et al. go on to state:

> Unquestionably, Mali has the greatest potential for irrigation among the Sahel countries of West Africa with a conservative estimate of over one million hectares of potentially irrigable land. The potential for irrigation is not evenly distributed throughout the country, but is concentrated in the Inland Delta and along the Niger River. (p. 33)

From a technical viewpoint, most of this land is undoubtedly cultivable under low-resource technologies, although Moris et al. do not disaggregate their overall estimate of potential. However, the issue remains the availability of financial resources and labor to support low-resource irrigation in many parts of Mali.

92) In Niger, Moris et al. estimate the irrigation potential to be 220,000 hectares, with most of it located in the Niger river valley. At present, Niger has about 9,000 hectares under management by the irrigation para-statal organization and 5,000 by small-scale private schemes. Realization of a large share of Niger's potential (140,000 hectares) is contingent on construction of the Kandaji dam. Only recently has the Nigerien government coupled encouragement of low-resource irrigation to its priority of developing large-scale, full-water control systems under the management of the irrigation para-statal agency. Hence, the real potential for low-resource irrigation development in Niger is difficult to estimate since it depends on policy decisions as well as the availability of social, economic and technical support.

93) Zimbabwe and Malawi are two other countries where all the necessary elements for rapid expansion of low resource irrigation are in place. The population densities in Malawi and communal areas of Zimbabwe are fairly high for Africa. Labor appears to be underemployed. Remittances from labor migration are already being used to develop low-resource irrigation schemes, and there is enough money circulating in the market economy to make irrigated production worthwhile.

94) Nigeria is another case where the convergence of a number of circumstances has promoted rapid expansion of low-resource irrigation. It has the high population of any African country, and the density is believed to be 96 per square kilometer, which

rivals that in many Asian countries. Thus, labor is abundant in principle. The oil boom of the 1970s made large sums of money available for domestic investment. Meanwhile, in the northern part of the country, especially in the Lake Chad basin, the water table is high, easy to tap and abundantly supplied. In addition, the oil boom has fueled demand throughout the country. Nigeria has an estimated .85 million hectares under irrigation (Tiffen 1986), more than half under low-resource technologies. A considerable share of this, particularly in northern Nigeria, has been developed during the last 15 years. However, the potential for further development remains an open question.

95) Hence, while the exact potential for low-cost irrigation technologies cannot be measured, it is certainly high where water is plentiful and inexpensive, soils are adequate from the standpoint of homogeneity, clay content and organic matter, sources of investment and operating capital exist in the economy, the labor supply is adequate and markets for the commodities produced are operating.

96) Among the low-cost irrigation technologies, diesel pumping is the most expensive. The less expensive ones--channeled, empoldered and water-lifting systems--have a more limited potential for expansion. Channeled and empoldered systems are technically possible in very particular environmental settings. On the other hand, installations of these two technologies are susceptible to technical assistance to improve their performance. Access to markets for their products would be an important

incentive for users to be receptive to incurring the cash and labor costs of intensifying production.

97) Water-lifting systems have the greatest potential in isolated areas, such as the semiarid regions of Chad, Niger and Sudan, which are technically well suited to pumping systems, but a shortage of labor and inaccessibility to markets limit production and preclude the generation of cash revenues to cover the higher investment and recurrent-cost burdens of pumping. Thus, production systems using water-lifting technologies are oriented more toward family, rather than regional, self-sufficiency.

C. Accompanying Changes for Wider Adoption

98) The three most important measures to encourage wider adoption of low-resource irrigation technology are:

- o initiation of rural credit programs to underwrite individuals and groups to implement irrigation schemes;
- o establishment of pools of technical expertise that individuals and groups can draw on for assistance; and
- o relaxation of policies and programs that distort the markets in production inputs and agricultural services and commodities.

99) The specific low-resource irrigation technology selected has implications for a number of factors, such as:

- o costs for development, operation and maintenance of the scheme;
- o social organization of management;
- o production, productivity and marketable surplus; and

- labor requirements for production and the allocation of family labor.

As noted above, like any agricultural production technology, low-resource irrigation is part of a larger system in which each of these factors is a consideration. The technology and factors form a pattern, and any given irrigation technology is compatible with a range of alternative matrices of these factors.

100) Thus, the particular irrigation technology chosen for a given site sets limits on the socioeconomic and managerial support systems as well as its economic outcome. However, the particular matrix of relations among system factors is unique for every irrigation scheme. Hence, the objective of promoters of low-resource irrigation is not to make a specific technological package available, but rather to make a support system available for individuals and groups to develop the package that best suits them.

D. Innovative Research

101) As has already been mentioned several times, the research that is most needed to encourage wider adoption of low-resource irrigation technology is studies of the role of irrigation in the farming system of the irrigation community. Such research should be a precondition for the design and implementation of an irrigation scheme.

102) A second area where innovative research is needed is on the appropriateness of pumping alternatives to certain socioeconomic and ecological circumstances. Many irrigation schemes have pumps

that are inappropriate to their needs and capacities. The choice of technology has implications for the size and organization of the group using it, and choice of commodities it produces for a particular marketing environment. It would be a great contribution to donors, host governments, NGOs and private parties involved in low-resource irrigation schemes to have guidelines on pumping alternatives and evaluations of specific pumping schemes in terms of their social, managerial, economic, environmental and purely technical parameters.

103) Another area for innovative research would be the development of new low-cost technologies to increase the performance of low-resource systems. This could include ways to increase the efficiency of the shaddouf used in the inter-dunal depressions of Chad, Niger and Sudan, and to reduce water infiltration in canals and water losses throughout the systems. These are the types of performance issues that should be addressed.

104) Research needs to be done on local institution-building. In addition, research is needed to develop a methodology for devolving management of low-resource systems controlled para-statal organizations to the users. Privatization is an increasingly pressing subject in many parts of Africa. Many low-resource systems in Niger, Mali, Sudan and elsewhere are excellent candidates for privatization.

105) The final area for study has already been mentioned several times, so it is hardly innovative. More needs to be known about

the groundwater hydrology of all areas in Africa where irrigation from wells is likely, including the vast area across the Sudano-Sahelian zone.

E. High Technology

106) Several high-technology methods have been tried to support low-resource irrigation. Two well-known experiments have focused on wind-driven pumps in Somalia and photovoltaic (PV) batteries in the Senegal Valley. In both cases, the technologies have not proven cost-effective at the present world market prices for diesel fuel. In addition, there is a maintenance and repair network for diesel motors and pumps in all African countries, often in relatively remote areas. Diesel technology is no longer exotic, which is not the case for windmills and PV. There are few mechanics skilled in maintenance and repair of the latter. In Somalia, one windmill experiment has been on hold for the last 10 months since the mechanic fell off it and broke his leg.

107) The risk of using high technology to support irrigation is that it adds costs to improve performance or expand coverage, thus sacrificing low production cost. Any technological innovation in the system will have costs not only in economic terms, but also for labor allocation, organizational requirements and management systems, for example. The implications of high technologies for each of these factors must be carefully considered before the technology is introduced.

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Appendix

APR 20 1987

April 15, 1987

MEMORANDUM

TO: Office of Technology Assessment, Bruce Horwith: OTA Project File

FROM: Associates in Rural Development, Abe Waldstein

SUBJECT: Respose to questions from our meeting of March 3

From my notes of our meeting I see that I have five points on which I should respond:

1. Re-explain the notion of the "barrage" in West Africa as a water lifting technology. (mentioned on page 10)

"In addition there are a number of systems in northern Togo, northern Ghana and throughout Burkina Faso which are fed from village barrages that store rainwater runoff. Burkina Faso alone is estimated to have more than 600 of these structures countrywide. In this part of West Africa, the terrain is very uneven and is criss-crossed with seasonal streambeds that can easily be dammed. The presence of a body of water raises the water table in the adjacent land. People are usually able to irrigate plots on that land by hand-bailing from shallow wells. People also often use small portable pumps to draw water from the retainment into the canal systems of their plots.

"Along seasonal streams that feed tidal rivers in West Africa people practice tidal irrigation which, in effect, is the converse of the barrage systems with, however, the same technology. River water levels rise at high tide year round. At flood season, when the rivers are full from the runoff from the rainy season, the river levels rise exceptionally high at high tide. Fresh water is then forced up into streambeds along the river upstream under pressure from the rising level of salt water downstream. People build small retainments for the fresh water to raise the water table in adjacent plots. Women usually use shallow wells to irrigate these plots. Tidal irrigation is very common in the middle reaches of the Casamance River, the Gambia River and the Geba River, for example.

"Barrage systems exist in eastern and southern Africa as well. During the 1970s, Kenya had a program to construct underground dams to raise the water table to permit shallow well irrigation."

2. The table of irrigation acreages in Africa from the International Irrigation Management Institute, AN AFRICAN STRATEGY FOR IIMI, by C.L. Abernethy and D. Berthery, 1986,

p. 46, Table 1. These are irrigated areas for 36 tropical African countries in 1982 according to FAO estimates.

Country	Irrigated Area (hect)	country	Irrigated Area (hect)
Sudan	1,700,000	Burkina Faso	30,000
Madagascar	960,000	Gambia	30,000
Nigeria	840,000	Benin	20,000
Senegal	190,000	Cameroon	20,000
Guinea	180,000	Liberia	20,000
Mali	150,000	Malawi	20,000
Zimbabwe	150,000	Mauritania	20,000
Tanzania	140,000	Niger	20,000
Ethiopia	110,000	Zambia	20,000
Sierra Leone	100,000	Angola	10,000
Somalia	80,000	Botswana	10,000
Mozambique	70,000	Burundi	10,000
Ghana	60,000	Congo	10,000
Ivory Coast	60,000	Mauritius	10,000
Swaziland	60,000	Rwanda	10,000
Chad	50,000	Togo	10,000
Kenya	50,000	Uganda	10,000
Zaire	40,000	Cape Verde	2,000

No data is provided for the Central African Republic, the Comoros, Equatorial Guinea, Gabon, Guinea Bissau, Lesotho, Sao Tome, Djibouti and the Seychelles

3. Fill in table beginning page 22.

type of system	location	number of users	area (hect.)	number of schemes
1. Channeled				
	East African Highlands		117,000 (Tanzania) 900 (Kenya) 5,000 (Malawi)	
	Madagascar Highlands		700,000	
	Middle & Lower Shabelle (Somalia)		16,000	
2. Empoldered				
	Upper Guinea Coastal Lowlands	700,000-900,000		
	South-east Lake Chad		4,000	
3. Water lifting				
	Sahel		6,200 (Burkina Faso) 2,500 (Chad) 14,500 (Niger)	600 +
	Coastal West Africa		10,000 (Gambia)	
	Southern Africa		400 (Zimbabwe)	
4. Water pumping				
	Zimbabwe	7,000	4,700	67
	Nigeria		800,000	
	Niger		36,500	500 +

Sudan	140,000
Chad	8,000

I have combed all the materials I have at home and this is the best I can do with this table. There are inaccuracies in the table because my sources did not disaggregate low resource irrigation technologies in the way I did. Good luck!!

4. a. Re-explain polder systems on page 5.

"Those of the Upper Guinea Coast are built on low-lying, swampy plains, intersected by a network of channels, which drain fresh water to the sea in the rainy season. In the dry season, after harvest, sea water is permitted to enter the polders to maintain soil plasticity. The advent of fresh water in the channels with the beginning of the rainy season washes the salt water out of the polders and leaches the salts out of the soil. The polders are then closed to the sea and crops are planted. Farmers use the residual moisture from the river water in conjunction with rainfall to irrigate their field crops. After harvest sea water enters the polder again, (Linares, 1970, 1981)."

4. b. Re-write status of polder systems on page 9/10.

"Because of their particular ecological requirements, only limited extension of these systems is possible. USAID is currently considering an irrigation improvement project focusing on the polders of southern Senegal. Operation of the polders requires a five month rainy season, in effect. The admission of salt water into the polders is vital to maintaing the plasticity of the soil. If the soils dry out entirely they will become uncultivable. The first two months of the rains flush the salts from the polders. The last three months are for crop production. A reductiion of the length of the rainy season, as hs been happening over the last decade and a half, threatens the viability of the system unles fast maturing but otherwise well adapted varieties can be found. Meanwhile, in the Lake Chad region, the drop-off in rainfall has led to a fall in the lake level to the point where the waters no longer reach the polders."

5. Come up with citations or give examples of actual benefits.

In the following water pumping and water lifting schemes, already cited, irrigation makes cultivation possible in the dry season where it would otherwise not be possible:

1. barrage retainments in Burkina Faso, northern Ghana, northern Benin, northern Togo.

2. pumping schemes along the Senegal in Senegal, Mali and Mauritania, the Chari in Chad, the Niger in Mali, Niger and Nigeria, the Komadougou/Yobe in Nigeria and the Nile in Sudan.

3. shallow well irrigation of depressions in high water table areas such as in the niayes in Senegal, the goulbis, dallous and dallols in Niger, the vleis in Zimbabwe, the dambos in Zambia, the fadamas in Nigeria, the ouadis of Chad, Niger, and Sudan, etc.

FINAL DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

OTA TECHNICAL PAPER SERIES:
INTERCROPPING IN LOW-RESOURCE AGRICULTURE IN AFRICA

by

David J. Andrews
University of Nebraska

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January 1987

FINAL DRAFT

OTA Technical Paper Series:
Intercropping in Low-Resource Agriculture in Africa

David J. Andrews[1]

ABSTRACT

1. Summary. Intercropping, where two or more crop species or varieties (limited in this discussion to annual crops) are grown mixed together on the same ground for all or much of their life cycles is a widespread age-old practice in traditional African food production agriculture. Almost all crops are intercropped to some extent--13 to 81% for 15 major crops in Uganda--and some crops are mostly grown intercropped, for example, cowpeas. Percentage crop land intercropped ranges from 42-83% in countries as far apart as Swaziland (Magagula et. al., 1979) and Burkina Faso (Delgado, 1978). As far back as 1934 in East Africa, Leakey advocated research on intercropping for food production but until the last two decades most food crops research in Africa has been on sole crops. This is partly because research objectives are more easily identifiable for single crops and research focused on cash crops, such as cotton, which are less suitable to intercropping and partly because research decisions were made by expatriate scientists whose temperate-region background caused them to think that production improvements could more easily be obtained from sole crops. The recent increase in intercropping research (Table 1) which has included some support from international agencies, particularly the IARC's, has come from the realization that in low-resource agriculture especially, diversity is valuable, stability of production important and maximum use of limited resources necessary. It is noteworthy that intercropping is not a new technology which needs to be introduced--indeed it probably arose wherever man began cultivation (Plucknett and Smith, 1986), but it is a well proven

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technology in use which can be a basis for improvement.

2. Message. Intercropping is the most dependable, widespread, long-established proven cultivation technology for low-resource African farmers. For the future well-being of this large group of people, support for increased intercrop production, possible in a number of ways, is needed through improved government policies, assistance programs, education and training, and research.

DESCRIPTION

3. Intercropping, also known as mixed or association cropping, as defined by Andrews and Kassam (1976) is where two or more crops are grown simultaneously in the same field. Crop intensification is in either the time and space dimensions or both. There is intercrop competition during all or part of crop growth. Various types of intercropping are recognized:

Mixed intercropping:	no distinct row arrangement.
Row intercropping:	crops in rows, either adjacent rows of different crops, or mixed within the row.
Strip cropping:	crops grown in different strips wide enough to permit independent cultivation, but close enough to interact agronomically.
Relay intercropping:	growing two or more crops simultaneously during part of the life cycle of each. A second crop is planted after the first crop has reached its reproductive stage of growth but before it is ready for harvest.

Intercropping is one of two major forms of multiple cropping (or crop intensification), the other being sequential cropping where crops are planted (or ratooned) successively in the same year, with no significant overlap in time of different crop species.

4. Intercropping provides a number of benefits:

a) Reduces risks both biological and economical, is flexible, and improves stability of production.

b) Increases yields per unit of land by making better use of resources including the family labor source.

c) Socially beneficial, spreads and increases labor demands, improves labor efficiency at critical periods and increases returns to labor when opportunity costs is low (Francis and Harwood, 1985).

d) Environmentally superior, reduces erosion and runoff, and improves disease pest and weed control.

5. Norman (1974), Abalu (1976), and Lyman et. al. (1986) conclude that the principal reason why farmers have adopted intercropping is reduction of risk, i.e. reliability (stability) of production is increased. Intercropping has been shown to reduce production variability (Francis and Saunders, 1978; Rao and Willey, 1980). Many aspects of crop to crop, crop/environment interaction contribute to this. Plants of the different species compete for growth resources and one may naturally compensate for deficiencies in growth of the other. Frequently, the crop components are not planted at the same time and should the first appear to be poor, the farmer may compensate by increasing the density of the subsequent crop(s). There is some evidence of reduction in pest and disease attack in crop mixtures (Altieri and Liebman, 1986) and weed growth which are frequently serious causes of yield losses and major sources of risk in sole crops.

6. Yield increase from intercropping arises from the fact that two or more species/varieties can more efficiently use space and time than a single species. Because different species have slightly different ways of using the environment, intercropping permits the 'border' or 'edge effect' between them to be exploited

throughout the field. The crop components of an intercrop can be divided into dominant species (e.g. a tall cereal such as maize) and dominated species (such as beans). The bean yields may be decreased by competition from the maize, but if this is more than offset by the yield increase of the maize, then the sum of the interactions is positive. In other cases, farmers may have different yield goals and require the full yield of the main crop, with an additional or 'bonus' yield from the second crop. In this case, the normal sole crop plant density of the main crop is maintained and only certain other non-competitive intercrops permitted such as relay cowpeas in millet or sorghum. Yield benefits of intercrops may, of course, be judged by various standards but economic worth or nutritional values are best. Yield benefits from intercropping average 15-20%, sometimes more depending on the situation (Willey, 1979). If this doesn't seem substantial it should be recollected that reduction of risk is probably the farmers prime objective in using this technology, and that other benefits can be significant, not least erosion control and preservation or improvement of the resource base. The time dimension may be exploited when the two species interacting have different life cycle lengths, and the competition between them is reduced, particularly during critical growth periods. A good example is the pearl millet/traditional variety cowpea intercrop of the west African Sahel. The millet is planted with the first rains and the cowpeas only when the millet is well established and as a result, cowpeas offer little competition to the millet. The cowpeas are at first suppressed by the millet but this is of little consequence since they can only begin to flower after the rains finish and the millet is senescent. Being of an indeterminate type, the cowpeas continue to grow and flower after millet harvest as long as stored soil moisture is available. In a season where the rainfall is below average, cowpea pod yields will be low, but there will be hay for animals. In good rainfall years, the system has the flexibility to utilize the extra moisture to the full with repeated harvests of cowpeas and, thus, the total growing season whether short or long is always completely utilized.

7. Intercropping reduces labor bottlenecks and gives a better return for labor time invested (Norman et. al, 1981). Indeed Norman's data suggest that farmers are prepared to contribute more labor time per hectare to intercrops than sole crops--probably in recognition of better returns.

8. Intercropping is an environmentally superior practice to sole cropping in a number of ways. With the intensity of tropical storms, soil erosion is a major factor in resource degradation. Aina et al. (1977) showed that intercropping maize in cassava on a 15% slope reduced erosion relative to cassava alone by 38% and runoff by 37% (with a consequent increase in moisture availability). Sesame is only planted on sandy soils in western Sudan when sorghum or millet plants are large enough to shield the sesame seedlings from abrasion by sand particles driven by the wind. Intercrops usually remove more nutrients than sole crops but explore a larger soil volume. Nutrient use:biomass ratios usually remain the same for crops whether sole or intercropped, and intercrops generally produce more biomass. On the other hand, residual effects of intercrops are more positive than negative (as with cereals) particularly when legumes are involved. Unless legumes are earlier maturing than the cereal, there is no fixed nitrogen transfer from the legume to the cereal but there is the beneficial residual effect of the legume on the following cereal, whether it be in an intercrop or a sole crop. This might be less than from a preceeding legume sole crop but there are usually compelling pest or disease reasons why legumes are not generally grown as sole crops by low-resource farmers. Weeds are more suppressed in intercropping (Hart, 1974) and, hence, there are less carry-over problems as is also the case with pests or diseases relative to sole

crops.

9. Intercrops may often involve a large number of different species, particularly in compound situations and where moisture is available throughout the year. A single farmer may also grow a number of species in small amounts to supply the family needs, e.g. spices and medicinal plants, as quite minor components of intercrops, without having to establish special nurseries or gardens. This also contributes to the preservation of species and crop diversity at the farmer level. However, frequently two or three species form the majority of the intercrop, and often these involve cereal/legume mixtures which have beneficial rotational effects on subsequent cereals.

STATUS OF INTERCROPPING

10. Geographic distribution of adoption. Intercropping is a ubiquitous practice in food production systems in Africa and is found to a significant extent in all agroecological zones (Francis, 1986a). Intercropping is not restricted to annual crops, indeed permanent tree intercropping with annual crop/intercropping is a basic feature of the west African Sahel, the driest of Africa's cropped zones. Okigbo and Greenland (1976) provide a description in some detail of intercropping in various agroecological zones in Africa ranging from semi-arid regions (250-750 mm annual rainfall) where pearl millet or sorghum with cowpea mixtures are common as in West Africa, through the derived forest zone (750-1500 mm/year) with maize/cowpeas, or maize/beans. In humid zones (1500 mm/year or more) root crops (yams, sweet potatoes) maize, and other legumes are mixed and perennial crops become involved (e.g. bananas) with a higher number of different species and with more relay and sequential cropping. Intercropping is not restricted to lowlands--numerous references are given to intercropping in higher elevations in east Africa and Ethiopia.

11. Extent of adoption. In different agroecological zones there are many

descriptions of intercropping, but relatively few quantitative studies. Steiner (1982) indicates that on an average, 80% of the land cultivated for food in west Africa is intercropped. Delgado (1978) reported 83% for Burkina Faso. Spencer (1973) observed that 91% of the upland rice crop in Sierre Leone is intercropped with cassava, maize, cotton, pigeonpeas and okra. Norman et. al. (1981) gives examples of three different areas in northern Nigeria where 54, 77, and 81% of crop land was intercropped. Fifty percent of seven major food crops in Uganda is grown intercropped (Jameson, 1970). In Swaziland, 43% of traditional farmland is intercropped (Magagula et al., 1979).

12. Types of farmers using intercropping. Intercropping is not scale neutral, it is more favored by the smaller farmers who wish to produce several staple food crops from a limited land area and, in particular, need to get the best return for their time and labor. The amount of land a family can cultivate by hand is limited by how much can be weeded at peak periods. However, it is a technology amenable to substantial improvement in terms of utilization of existing component technology, e.g. new varieties, fertilizer, pest and disease management, animal traction, and even partial mechanization. Improvements to existing intercropping practices at the small holder level will be more readily acceptable than attempts to introduce sole cropping (Fussell et al., 1986). The older biases against intercropping--the belief that it is a technology tied to the hoe--are diminishing as the benefits of intercropping are more clearly understood and as examples of the use of intercropping at intermediate and higher levels of crop intensification are demonstrated. Indeed animal traction has been integrated with row intercropping for centuries on the Indian subcontinent and the Chinese currently utilize intercropping principles at the highest levels of intensive cropping.

13. Status within major development agencies. A number of major development

agencies have supported research on intercropping, usually as a component of farming systems research. USAID/Africa has been giving increased support to farming system types of research and to understanding existing low-resource agricultural production, but AID does not have any projects dealing principally with intercropping. About 10 countries in Africa have AID funded projects where intercropping is a feature and all agroecological zones are represented. IDRC has supported intercropping research worldwide and currently has six projects on annual crops in five African countries. IDRC (1976, 1978, 1982) has funded three workshops, two at Morogoro, Tanzania 1976 and 1980, and at Trivandrum, India, 1978 (on cassava intercrops). One of the series on agricultural symposia conducted by the Ford Foundation in 1970 at IITA, Ibadan, Nigeria, addressed intercropping. The American Society of Agronomy conducted a symposium on multiple cropping (ASA Special Publ. No. 27, 1976). Among the IARC's, IRRI, CIAT, IITA, and ICRISAT all have strong intercropping research programs and ICRISAT hosted an international workshop in 1979 (ICRISAT, 1979). Reference is again made to Table I which illustrates the increase in intercropping research in the last 20 years.

14. Costs, negative impacts, constraints. Intercropping suffers from the same multitude of constraints as do other forms of low-resource food production agriculture. It is practiced and relied on for subsistence by individual families in unorganized groups without capital often using only hand implements. Access to agricultural inputs, credit or information is poor and markets for any surplus are notoriously unreliable. Vis-a-vis other forms of low-resource agriculture, intercropping imposes no constraints in regard to access to land, or different stratification by household, age or gender. Intercropping is a technology more favorable to smaller farmers but research has repeatedly shown that it can be a desirable practice and can be improved. However, since the

principal concern of small farmers is avoidance of risk, new interventions should be carefully evaluated for their risk consequences. Those which might reduce risk would likely be accepted. Intercrop combinations (not the practice of intercropping itself) are relatively site specific and thus improvements to them will need research in situ. However, the existing practice in a locality constitutes a very clear basis for comparison to determine the effect of any given intervention.

APPLICATION OF OTA'S PRINCIPLES AND CONCEPTS

15. See Table 2.

SHORT- AND LONG-TERM U.S. AND NON-U.S. POLICY ISSUES

16. Intercropping is fundamentally involved in rainfed African food production agriculture at the small holder level. It has potential at intermediate technology levels but has less relevance at the larger scale mechanized farm level. Intercropping has and will continue to play a key role in alleviating the food crisis in many African nations and has important social and political implications. Many such countries do not have the industrial or non-farm employment capacity to absorb labor moving off the land. In this context, indigenous food production must be increased by increasing labor efficiency and not by labor displacement. Thus, labor-saving innovations are not required. Intercropping has been shown in Africa to more efficiently employ labor than sole cropping and improvements to it, such as animal traction, increase labor efficiency (McIntyre, 1983), provided land is not limiting. Intercropping tends to be focused more on staple food crops than cash crops such as cotton and tobacco which do not interact well with other species. Other crops such as groundnuts, soyabeans and sunflower can be intercropped but when grown as a cash venture in Africa are often grown as sole crops or with limited participation of other species.

17. Constraints

a) Relatively new research area.

b) Complexity of topic.

c) Notion that intercropping can only absorb technical changes specifically researched for intercropping, e.g. new varieties (but see f below)

d) Difficulty of research--the majority of the plant interactions probably take place below ground.

e) Potential use of herbicides restricted.

f) The component species which are dominated in a mixture are likely to show greater differences between varieties in an intercrop situation. It would be necessary to more carefully choose (or breed) varieties of such species for intercrop situations.

g) Some interventions are possible on broadcast intercrops but reorganization into rows would be needed for others to be used.

18. Opportunities

a) Offers opportunities to increase labor efficiency, and, hence, total income.

b) Can absorb some existing new technologies with relatively little adjustment, e.g., responses of cereals to fertilizers, except at very high levels are similar whether sole cropped or intercropped. Andrews (1972), Baker (1979) and others subsequently have shown that yield benefits of intercropping can still be exploited at higher management levels. New sorghum varieties, developed for sole cropping, were also superior in intercrops (Andrews, 1974) and the higher total intercrop yields resulted both from the new varieties and the interaction with the other crop component. Through breeding varieties specifically for an intercrop situation (Francis, 1986b) would be the optimum approach, it is a long-term solution. Much can be immediately obtained by testing and selecting among the existing range of phenotypes for the best combinations. Animal traction appears to be an acceptable intervention for intercropping (traditionally used in Asia) which would have favorable consequences for women--reduction of weeding needs, and a means of load transportation. Methods of agronomic research on intercropping have been studied and are well reviewed by Willey (1979) and Parkhurst and Francis (1986). Priorities often quoted are improved varieties, plant density and planting dates, fertilizer or manure use, and use of animal traction (involves shift to row cultivation).

19. Cautions. For reasons already stated there is less direct conflict of interests between intercropping and commodity research, where the latter refers to a 'cash' crop, e.g. cotton. However, there is a conflict as far as competition for research capability and other types of support are concerned. Some rationalization of policy is required here. It could be argued that if the commodity was produced from intercropping to an appreciable extent, then the research project should incorporate intercropping as a major feature in testing. A more substantial reason, however, is that knowledge, research investment, and extension effort are grossly inadequate for intercrops vis-a-vis the amount of food produced from intercrops as against sole crops. Intercropping is not a simple technology, like fertilizer application, but is a system--a synthesis of components, adjusted and refined to meet local needs. It usually involves the whole family, men, women, and children and sometimes hired labor Some individual components of the system have more important effects than others, and there is an absolute need to determine which are the major constraints which are

also recognized by the farmer, and what will be the possibilities and consequences of alleviating them. For instance, weeds are often cited as a major constraint and animal drawn implements as a control method. Besides the technical difficulties of doing this (animal management + care, equipment cost and maintenance) diverse other effects must be considered such as benefits of manure and land preparation, employment opportunities for displaced labor, reduction of time needed to haul water and fuel wood when animals can be used. It should not be overlooked that intercropping, like any other crop production system in low-resource agriculture is very responsive to input costs and market availability--particularly stability. It has been frequently demonstrated that low resource farmers can respond remarkably to the incentive of stable prices without any other type of intervention (vide the 20,000 tons of surplus pearl millet produced by small holder farmers in Zimbabwe in 1983/84 crop season in response to favorable grain prices being fixed before planting).

POTENTIAL OF THIS TECHNOLOGY

20. The report from FAO (1978) show that under 'high input' conditions, Africa could produce four times as much food as it does now. With only a fraction of the more appropriate of these inputs--new varieties, some phosphate fertilizer, animal traction, and manure, traditional farming (includes intercropping) can give substantial increases in production. This will not happen, of course, unless governments have the will and the means to stabilize food market prices at a level attractive to the farmer. Food production in African can also increase through expanding the area cultivated--this is apparently already happening. However, although there is more land available than in use, what is being used is the best and generally progressively poorer land will be cultivated with resultant loss of sustainability. Intercropping has been shown to protect the resource base better than sole cropping and is more efficient per

unit of land. All land in Africa, or in small holder farming, does not have to be periodically fallowed. Properly managed suitable land can be continuously productive and there are instances, where intercropping is a common practice, when land has been cropped for several decades.

21. A projected rate of change is highly speculative and difficult to quantify, but there is little doubt that it will be tied to many of the same factors which constrain most low-resource agriculture, particularly poor levels of government support.

22. The question is not so much of how the percent of land to intercropping will increase, but can intercropping absorb and utilize new technologies as well as sole crops. As long as the majority of farm sizes remain small in Africa (and, until sufficient alternative non-farm employment is generated in a country this seems a political necessity), production per unit of land and labor will remain important. This will favor the retention and spread of intercropping. Research must, therefore, focus on ways to improve intercropping. As previously stated, this should involve:

Plant nutrition--mineral fertilizer and manure.

Timeliness and weed control--animal traction.

Plant density/intercrop arrangements and relative planting dates--attainment of best complementary and resource use.

New varieties--attainment of best complementary resource use by experimenting with the incorporation of new varieties.

Animal traction--for cultivation, weeding, transport, and manure.

23. Intercropping is amendable to improvement by the judicious application of many of the same practices used to improve production on the same individual crops involved. These were listed in paragraphs 18 and 22. The use on animal traction and some use of fertilizer will provide the greatest benefits, since

this will permit more timely operations, better seedbeds and crop establishment, better weed control and moisture and nutrient use. Since these are the same major constraints that restrict sole crop production, there is little conflict in research priorities in this area. The constraints of poor and unstable markets apply to production from intercropping just as from sole crops. As with sole crop production, the crop cultural type research will be easiest to do in the short term and be the most effective in increasing production from intercrops. Research on genotype interaction between species in intercropping (excluding effects of planting date, plant density and proximity adjustments) which has loosely been called breeding, falls into two categories:

a) choice among existing genotypes, and

b) actually breeding for new genotypes specifically adapted to a described intercrop situation.

There is usually a sufficient wide range in choice of morphology and duration of the two (or more) species to be intercropped, so that good compatability between the two can be obtained, which, of course, can be further adjusted by means of different planting dates, and relative plant numbers. Thus, there would be few situations, when a near optimum situation cannot be obtained with genotypes already available, where breeding for a specific intercrop situation would then be warranted. As has been previously noted, the benefits of sole crop genotype improvement by be also realized in intercrop situations. Francis (1986) describes tests to measure the probabilities of varieties which are best in monocrops also being best in intercrops. Sometimes these probabilities can be low, indicating that only a few varieties are good in both systems, but though this would indicate a case for actual breeding, the potential yield loss is not defined, as there still may be adequate phenotypes in the few varieties available. The conclusion, therefore, is that though genotype x cropping system interactions would indicate breeding to be the optimum approach in some intercrops but it is likely that near optimum combinations can be obtained by choice among existing lines, if an adequate number are available. This, is research that can be concluded in a short period, 3 or 4 seasons, whereas breeding will take longer and also is subject to some restrictions as to the specific intercrop situation which is chosen and the consistency with which it can be reproduced. These difficulties have resulted in little progress being reported from actual selection work, and most being achieved by testing choices of combinations between varieties (Willey and Rao, 1981).

24. Apart from on-farm research designed to give results of immediate use by extension services, there is a need to more clearly understand how intercropping works--what is the nature of competition between species over the season, and what are the long-term effects. The most needed area of research here is below ground--competition for soil moisture and plant nutrients and resultant soil changes. Thus support is also needed for basic research at institutions capable of using the most advanced research technologies such as neutron probes and isotope labelled fertilizers needed to study below ground interactions.

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Table 1. Accelerating Research on Intercropping
As Illustrated by Numbers of Publications on 14 Crops by 5-year Period Up to 1980 in ICRISAT Resource Lists

Crop	First publication	Number of publications							
		Pre-. 1950	1951–1955	1956–1960	1961–1965	1966–1970	1971–1975	1976–1980	Total
Cassava	1917	5	1	4	1	4	25	44	84
Chickpea	1914	2	3	2	21	10	5	23	66
Common bean	1956	0	0	3	0	1	14	41	59
Cotton	1940	8	8	19	18	14	28	38	133
Cowpea	1949	1	1	2	5	9	38	123	179
Groundnut	1937	9	4	9	17	14	25	100	178
Mung bean	1954	0	2	0	5	12	30	98	147
Pearl millet	1943	3	1	0	5	11	23	71	114
Pigeon pea	1943	6	4	2	1	4	30	91	138
Rice	1942	2	1	5	4	5	34	35	86
Sorghum	1941	7	4	15	20	21	52	145	264
Soybean	1937	6	2	7	31	20	53	108	227
Sugarcane	1933	2	7	6	18	16	53	40	142
Wheat	1929	9	4	11	50	22	30	43	169
Total		60	42	85	196	163	440	1000	1986

Source: Dr. M. R. Rao, 1984 (unpublished). From: Francis (1986).

Table 2. Application of OTA's principles and concepts to intercropping.

What needs to be done	How to do it	Who should do it	What limits it
Principle A--Components in African Low-resource Agriculture			
Institutional and economic support are components most lacking, both for farm inputs and market support.	Work with govenments to revise policies and improve extension capability serving intercrop production.	National governments and assistance agencies.	-government planning ability -agricultural supply infastructure -number of extension staff
Principle B--Linkages in African Low-resource Agricultural Systems			
Preserve and increase linkages.	Establish integrated interdepartmental projects that consider ecological, social and economic consequences of proposed improvements to intercropping.	Assistance agencies or IARC's, working with national research centers and government departments.	Staff numbers. Reluctance of departments to participate in interdepartmental or interagency collaboration.
Principle C--Low-resource Farmers and Herders Responses			
Assistance should emphasis farmers current skills and knowledge.	Determine that improvements to intercropping will not restrict farmers flexibility. Monitor proposed improvements as in Principle B.	National government departments and research centers.	-staff -project identification -belief that farmers do not have sufficient skill and and ability.
Principle D--Use of Local Resources			
-Characterize local intercropping practice	-Farm surveys over time	-National staff and assistance agencies	Staff numbers and lack of knowledge of potential of local resources.
-Determine major constraints	-Talk to farmers including women, prioritize constraints.	-National research and extension staff	
-Build on intercropping's use of local resources	-Conduct field research at farm level.	-National research and assistance agency staff.	

Table 2. Application of OTA's principles and concepts to intercropping (continued).

What needs to be done	How to do it	Who should do it	What limits it
Principle E--Heterogeniety of Low-resource Agriculturalists			
Determine how policy changes will affect various classes of agriculturalists.	Conduct socio-economic studies.	IARC's and national centers.	Staff numbers.
Principle F--African Women Play a Key Role in Low-resource Agriculture			
Involve women in planning.	Ensure women are members of policy planning groups.	National departments	Number of trained women.
Determine effect of policy implementation on women.	Ensure benefits are equitable by gender.	National staff.	
Increase role of women in ag. research, extension, and training.	Increase training of women.	Assistance agencies, and national education system.	Numbers of candidates.
Principle G--Sustainability of Systems			
Improve sustainability aspects of intercropping.	Design changes to improve resource base and social benefits.	National and assistance agencies.	Lack of priority, poor recognition of need to preserve resource base and evaluation of long-term effects.
Principle H--Local Participation			
Design locally appropriate improvements to intercropping.	-Ensure local staff and especially farmers are fully involved.	National staff.	-Staff numbers and understanding.
	-Conduct on-farm research to develop appropriate technologies.	Assistance agencies with national staff.	-Research capability
	-Realistically review recommendations.	National staff, IARC's	-

FINAL DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

OTA Technical Paper Series: Intercropping

CHALLENGES OF INTERCROPPING: POLICY ISSUES

by

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FINAL DRAFT

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Low-Resource Agriculture in Africa

OTA Technical Paper Series: Intercropping

CHALLENGES OF INTERCROPPING: POLICY ISSUES

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ABSTRACT

1. Summary. Intercropping describes a broad range of systems which include two or more crop species in the same field for all or a part of their growth cycles; it is a subset of the more inclusive term "multiple cropping", which is an umbrella term describing all systems where crop culture is intensified in time and/or space, and two or more crops are harvested from the same land area each year (Andrews and Kassam, 1976; Francis, 1986). These complex systems likely represent the first human farming experience, and our modern sole cropping patterns are a relatively recent development in agriculture (Plucknett and Smith, 1986). Intercropping is widely practiced in most of the developing world today — perhaps 50 to 80 percent of the land in Africa is dedicated to this practice, and a higher proportion of the food crops are grown in complex intercrop systems (for references see Andrews, 1986; Francis, 1986). These systems are important because they are indigenous to the region and farmers have experience with them, because they make efficient use of resources internal to the farm, because they produce a range of crops and products for home consumption and for sale, and because they minimize the risk for low-resource farmers and families

(Francis, 1985). Intercrop systems are used primarily for growing food crops, an important responsibility of women in Africa. There is great potential to improve the productivity of these systems and their return to labor, and through research to understand the complexity of plant/plant interactions and the benefits of rotations and integrated cropping systems under limited resource conditions (Francis et al., 1986). Intercropping is an important dimension of the quest for appropriate technology and solutions to the African food challenge.

2. Important Message. Development strategy employed by the U.S. and other major donors in Africa has emphasized reliance on high technology, dependence on fossil-fuel based production inputs, and adoption of cropping patterns and farming systems which have been successful in temperate and developed countries with sophisticated cash economies and an extensive natural resource base. The training of technical people and organization of institutions have been modeled after systems which have been successful in developed countries and different cultures in the first world. It is time that new and creative approaches are found to build on the unique resources and constraints in the varied climatic, geographic, cultural and political niches in Africa, and that professional colleagues and farmers in each country become full partners in the program. Intercropping is one example of an indigenous technology which is appropriate to the continent, which can be improved through science, and which can be encouraged and implemented through development policy to be an important part of the solution to the challenge of food production in Africa.

EVALUATION OF THE INTERCROPPING ENVIRONMENT

3. African Environment. A detailed description of intercropping in Africa and the physical, climatic, and cultural environment in which it is found is provided by Andrews (1986) in a companion paper, and that information is not repeated except where necessary for clarity. This discussion of the intercropping environment describes what is unique about African agriculture, and how this is important to policy decisions related to development. Although there are biological principles which apply to crops and systems throughout the world, there are certain complexities in the African context which have made it difficult to take technologies or packages "off the shelf", when these were developed in temperate regions, or even in the developing world under a different set of circumstances. This is important, because it helps explain why technology has not been easily introduced in many parts of Africa, why our current approaches have limited success, and consequently why food production per capita continues to decline.

4. Diversity of Resources. In Africa there is a great diversity in the land resource, as well as the amount and distribution of rainfall which brings potential to this land and soil. A lack of appreciation of this diversity on the part of policy makers leads to recommendations and strategies which take the form, "The solution to food production in Africa is ...". In fact, there is no easy nor single unique solution. Introduction of a technical package of crops and practices developed elsewhere, or even in a local experiment station under rigorous control and with high levels of

production inputs, is unlikely to have wide acceptance with farmers who work in an uncertain and difficult environment. Soils have been depleted for centuries in some parts of the continent, and the pressure of population to reduce the time of the bush-fallow cycle brings further pressure to already infertile soil resources (Timberlake, 1985; Brown and Wolf, 1986). The much publicized drought in recent years in the sub-Sahelian region and in the southern part of Africa is apparently documented now as a part of long-term cycles of dry and wet years; strategies for development need to include provision in cropping systems for this variation and diversity in climate — intercropping can help to reduce some of the risk inherent in sole cropping.

5. Realities of Global Economy. Current use of petroleum resources is dominated by those countries and sectors which can afford to purchase them. Dr. Vernon Ruttan, University of Minnesota, stated that "Many of the Third World countries have not effectively entered the fossil fuel era. Because of the scarcity and price of fossil fuel energy, it is likely that many of them will never enter this era" (quoted in Francis and Harwood, 1985). Even those supplies of fossil fuels which reach most developing countries in Africa, at a large cost in scarce foreign exchange, are utilized in higher priority activities in industry, transportation, and development of an urban infrastructure. Although one could argue that higher priority should be given to agriculture and to needed inputs, the reality is that farming will continue to be based on exploitation of internal resources found in the immediate environment. In this context, intercropping is one technology which can make effective

use of internal resources, while providing potentials which can be realized even in the absence of imported energy and industrially-produced production inputs (some of these potentials are described by Hart, 1986).

6. Environmental Realities. The causes and consequences of the current "environmental bankruptcy" in much of Africa are described by Timberlake (1985). It is not difficult to understand how and why national planners have been forced to make expedient decisions related to agriculture and food — there is an immediate need to produce more food, as quickly as possible, due to the declining supply per capita (U.N. Economic Commission for Africa, 1985). The need for regenerating this environmental capital is critical, as detailed by Brown and Wolf (1986), and the importance of agroforestry and annual/perennial crop systems in this process cannot be minimized (Gliessman, 1980; U.N. Food and Agriculture Organization, 1982; OTA, 1984). One example of a technology receiving increasing attention is alley cropping, where perennial legumes are planted in single rows from 3 to 6 meters apart, and annual crops are planted in the alleys between the perennials. Intercropping of annual crops provides a sustainable solution to provide food which is consistent with traditional wisdom and technology in many areas, as well as the constraints which face many farmers. This can be introduced more quickly than annual/perennial systems, and may find more rapid acceptance. It may take more time to demonstrate and move other perennial/annual crop systems, as they are developed to broaden the options available to farmers.

7. Current Adoption of Intercropping. The geographic distribution and extent of use of intercropping has been detailed by Andrews (1986). An early description of the importance of multiple cropping was prepared by Dalrymple (1971). More detail on the region-specific use of systems is found in the American Society of Agronomy Symposium Proceedings for Africa (Okigbo and Greenland, 1976), Asia (Harwood and Price, 1976), Tropical America (Pinchinat et al., 1976), and the Middle East (Nasr, 1976). It would be grossly incorrect to discuss "adoption of intercropping" in the same terms as the adoption of high yielding varieties of rice or of increased rates of nitrogen fertilizer. It is clear that complex multi-species systems were favored by farmers in much of Africa and elsewhere long before the change to sole cropping — it might be more appropriate to discuss the "survival" of intercropping and to explore the reasons. The biological and economic stability of these systems compared to sole cropping was described by Andrews (1986). Two quantitative studies of the increased stability of yield and income, and thus reduced risk, were reported for sorghum/pigeon pea systems in India (Rao and Willey, 1980) and maize/bean systems in Colombia (Francis and Sanders, 1978). In each case, the variance in yield and income across seasons or locations was greater in sole cropping of each component crop than in the intercrop. This is experimental evidence of why farmers preserve their traditional multi-species systems.

8. Current Research on Intercropping. There has been a surge in research on complex cropping systems, including intercropping. Much of the recent work is discussed in the books by Beets (1982), Gomez and Gomez (1983), Steiner (1982), and most recently Francis (1986). This flood of recent publications reflects an increasing appreciation of the importance of intercropping by the research community (see Table 1, Andrews, 1986), and a greater dedication of resources by organizations in development and research to improving these systems. Although the systems are primarily used by medium- and small-scale producers in all continents, and the results of research and recommendations are most likely to address the problems faced by low-resource farmers, much of the research has been conducted under more favorable conditions on the experiment stations. Research specialists trained in narrow disciplines have generally addressed research questions in their respective disciplines, and bringing sole crop experience and methods to intercropping has, at times, given technically credible but practically doubtful recommendations. In Colombia, for example, our initial research used varieties, densities, and pest control measures developed in sole culture of the same crops. It is important in the future that much of this research be conducted under the real constraints faced by the low-resource producer.

9. Current Posture of International Agencies and Research Centers. During the early decades of development assistance, the emphasis was on "modernizing" crop production by introducing those methods found successful in other regions — hybrid crops, synthetic fertilizers, chemical pesticides, irrigation where feasible. With the

establishment of the international centers in the sixties and seventies, a greater emphasis initially was given to crop improvement. Centers and research teams were given "world-wide mandates" to work with specific crops, to establish germplasm banks and world collections to supplement those of national programs, and to establish centers of excellence for research and training. Later, in some of the centers — especially IRRI, ICRISAT, IITA, and CIAT, projects were organized around multiple cropping, farming systems, and scale-specific methods which could be used by low-resource farmers. The centers are still exploring the balance which should be maintained between crop-specific research and both the applied and basic questions in cropping systems. An estimate by the author is that less than 30 percent of the current budget in the IARC's is spent on systems research. This is based on the numbers of senior staff assigned to "Farming Systems" or "Multiple Cropping" programs in the centers; it is a very preliminary estimate at best. It is difficult to assess precisely what % or $ amount is going into this research.

10. Status of Intercropping in U.S. Development Projects. It is difficult to estimate the degree to which U.S. bilateral contracts through universities and direct U.S.A.I.D. contracts are involved with intercropping. There is a recent acceleration of interest and involvement with whole farm systems, and "farming systems research and extension" have been important buzz terms for nearly a decade. In some cases, complex cropping systems have received attention within this context; intercropping has also been studied by some development scientists whose principal assignment has been a single

crop. Personal experience of the author suggests that a maximum of ten percent of research and extension efforts in agriculture involve some emphasis on intercropping — often as a part of some other activity. There is no precise estimate available, although a survey of centers and key project leaders might reveal a more quantitative estimate. Technical publications, books, and workshops in the past five years indicate that this area will receive greater attention in the future, as more scientists and research directors begin to appreciate the widespread importance of intercropping, and the reasons why most farmers have preserved these systems. The continuing importance of intercropping systems suggests that greater emphasis be given to complex cropping patterns in our international AID programs.

11. Negative Impacts and Key Constraints. Characteristics of farmers and their economic situation were described by Andrews (1986). With this limited resource base and lack of political clout, it is difficult for farmers practicing intercropping to bring much pressure on those within a national research or development program to influence priorities, and to move intercropping up in the research agenda. On the part of national planners, directors of research, and development specialists it could have been argued in the past that any attention given to intercropping would be a dilution of the thrust toward modernization and development of the agricultural sector. The assumption was that these systems would disappear with the introduction of "more productive" sole crop systems. This has not happened in most areas, and we need to find ways to improve the systems. This process is complicated because

many of our traditional approaches have not worked — mechanization and chemical weed control are difficult because of the multiple species of crops, soil fertility is more complex due to multiple needs of crops, relative priorities for insect/pathogen resistance versus other traits are different from monoculture. In summary, the constraints are different. Today, the attention given to the productivity of crop mixtures and the emerging realization that intercropping will be a part of the small farm sector for the forseen future is giving more confidence to those who support research and development efforts in this direction. As described by Andrews, there are a number of social and economic reasons why low-resource farmers choose to maintain these systems, to reduce risk and provide a varied and consistent food supply for the family.

12. Policy Issues Related to OTA Principles. The table of "OTA Principles and Concepts" prepared by Andrews (1986) is appended for reference, and the current discussion highlights policy aspects of each principle as listed in his table. A number of key policy issues were identified in the workshop on regenerative agriculture held in Washington in December, 1985, and this reference will supplement the present discussion (Francis, 1985a).

13. Principle A: Components in African Low-resource Agriculture. There is a host of deficiencies which limit the development of African agriculture — in education, research, extension, and overall development planning. Most of these are common to intercropping as well as to all aspects of other component technology. What is unique to intercropping is the lack of information in the curriculum where young technicians are trained, the lack of a strong research base for developing new practices, and the lack of orientation of the extension system toward whole farm systems and specifically intercropping. Until national decision makers, and those who provide support from outside, realize the importance of multiple crop systems there is little chance that this will change. This thesis has been expanded by Harwood (1979, 1983), who provides important resources for further information.

14. Principle B: Linkages in African Low-resource Agricultural Systems. A key constraint here is the strong tendency toward training specialists to work in each discipline — and their inability to focus on broader aspects of the entire cropping system as a result of this training. This is important both for those African scientists who have received specialized training and those technical persons involved in development assistance. The established reward system recognizes superior achievement by plant breeders, soil microbiologists, or insect pathologists within their narrow fields of interest — it is critical that emphasis be given to rewarding those in agronomy and development economics who are willing to break out of these disciplinary chains and tackle the more complex issues of cropping systems. This is an issue which can be articulated to policy makers at the national level, and one aspect of the system which could be resolved. It will be more difficult to develop the information base and get it included in the agricultural education agenda.

15. Principle C: Low-resource Farmers and Herders Response. Farmers do respond to innovative components of technology which meet perceived constraints to production and which are realistic within the economic and social context of their farming systems (Francis, 1985b). Often in the past, the recommendations to abandon intercropping, plant one or more sole crops, and purchase expensive and little understood inputs have not been accepted. Technicians have been left

wondering why? An emphasis on intercropping, building on the conventional wisdom and experience of the farmer, and improving those systems within the framework of traditional farm activities will be much better understood and adopted. Much of the change needed is with the research and extension technicians themselves, and the policy option is to include much more preparation and experience during their training and orientation. These are not simple changes! A successful link of science with traditional wisdom will require a better understanding of total crop/animal systems and a more sophisticated management than "green revolution" sole cropping.

16. Principle D: Use of Local Resources. This is a key element of intercropping and the successful adoption of modifications in existing systems. Well articulated by Rodale (1985; also see Francis and Harwood, 1985), the shift of emphasis from technologies dependent on external resources to those which maximize the use of resources internal to the farm will be easily understood and more readily accepted by low-resource producers. These systems are more economically viable, lower risk, and pose less hazard to the farm family and to the off-farm environment, compared to chemical-intensive practices. There are a number of policy issues related to credit for purchased inputs, government subsidies for specific inputs such as chemical fertilizer and pesticides, and types of recommendations which come from research and extension which

need to be addressed (Francis, 1985a). In the Cauca Valley of Colombia, the extension service has recommended replacing the multiple cropped parcels with maize and soybeans, two well-adapted commercial crops in the zone. The new monocrops require purchased fertilizers and insecticides, mechanization, and other costly inputs for which the farmer needs credit. If successful, harvest comes two times per year, and the family must manage the income from harvest to buy food and other needs during the next four to seven months. Although net income would appear to be greater from this new system, there are new risks with credit and inability to manage funds over a period of time. In contrast, the traditional system provides a series of basic foods (maize, cassava, beans, banana, papaya, pineapple, and others) as well as products for sale (coffee, cacao, some excess of other crops) which can sustain the family through the entire year. The farming systems approach can be useful in the evaluation of people's needs and specific constraints to production and the assessment of resources available locally which can be used to increase productivity (Gilbert et al., 1980; Hildebrand and Poey, 1984). The most important policy issue is the recognition that traditional systems are very much a part of the total culture and often well-suited to available internal resources — massive programs to "modernize" these systems must be carefully tailored to both people's goals and educational levels, and to the natural resource base. National programs must be designed with this in mind.

17. Principle E: Heterogeneity of Low-Resource Agriculturists. In a rush to recommend technical packages and specific crops/practices for each major crop, development specialists have too often ignored the tremendous diversity which exists among farmers and their respective resource bases. What is needed in further development efforts in Africa is a multi-faceted approach which takes into account the range of situations which exists, and provides a range of options from which extension specialists can recommend and farmers can choose. Although this is more complex than a blanket recommendation on how to grow rice or wheat, the approach is more likely to be successful in a wider spectrum of situations.

18. Principle F: African Women Plan a Key Role in Low-Resource Agriculture.. It is difficult to convince national planners and policy makers of the importance of women, long considered "invisible" in agriculture in spite of the vital role they play in the farming sector. Policies are needed which immediately recognize the crucial role of women in farming decisions and implementing practices, and which include educational opportunities to move more women into the national system. Until this is done, it will be difficult to find candidates for research, extension, and teaching roles in each country. There is a greater

awareness on the part of development agencies of the role and importance of women, and this is having an effect on the assistance from the U.S. government. Although quotas or specific rules are often constraining, it would be valuable to stress the selection and training of more women for key development roles, and to include more women scientists in the international center's research network.

19. Principle G: Sustainability of Systems. There has been a general lack of understanding and appreciation of the environmental aspects of African agricultural development, and the consequences are becoming felt with increased population pressure (Timberlake, 1985). Policies need to be studied, developed, and adopted which take into account the immediate and long-term effects of agricultural practices and recommendations on the farming environment and the soil resource base. Many of the practices which can be incorporated into improved intercropping systems are consistent with improving the soil resource, including reduced tillage and residue management, rotation of crops, alley cropping, and incorporation of legumes and cereals into the same intercrop. Farmers currently use and preserve these systems for their lower risk and greater sustainability, of food and income.

20. Principle H: Local Participation. The development of improved intercropping systems and the introduction of these changes on the farm are not activities which can be dictated

from top down. Although a research and extension policy which encourages development of these options is vital, the actual work on alternatives and the testing under real world conditions must be done in the field, and preferably will be done with full farmer participation. Again, the farming systems approach provides some guidance for how this might be done, with regular communication between technician and farmer and early testing of ideas on the farm. There is a high degree of location and resource-level specificity in intercropping systems, and this is another reason to involve the farmer from the first stages of each project. Many scientists argue that on-farm research is costly, high-risk, and without control over experimental variables. Although all these arguments are valid, we sometimes maintain a bias toward station reserach because of lack of courage, experience, and appreciation of the vital need to work under the same constraints which face the farmer. Much greater emphasis is neaded on FSR and on-farm research/extension activities, with station research reserved for only those specialized activities which cannot be done elsewhere.

U.S. AND NATIONAL HOST GOVERNMENT POLICY ISSUES

21. Constraints to Improved Intercropping. The Andrews (1986) paper discusses constraints related to the complexity of intercropping systems and the location- and system-specificity of results. As more work is carried out under controlled research conditions and a better picture of how precise interactions function, these constraints may be overcome. Especially useful will be surveys and precise measurements made under farmer conditions, in collaboration with the producer/decision maker on the farm, and this collaboration can include help in the interpretation of the data. Most research training fails to include developing an appreciation of what the farmer knows from past experience, and this is a shortcoming in our research methodology which needs to be overcome. In addition to the constraints listed by Andrews, several others need to solved:

a. Lack of precise research methodology for study of intercropping: recent contributions by Mead (1986) and Parkhurst and Francis (1986) provide some guidance, and a book by Federer (personal communication) will be excellent in this area.

b. Continued lack of appreciation of the importance of intercropping by policy makers in agriculture and technical assistance teams.

c. Lack of experience in practical intercropping systems by national program scientists, teachers in agricultural high schools, colleges, and universities.

d. Absence of interest in intercropping from the commercial sector — especially in the development of systems dependent on internal resources: this provides no additional market for commercial fertilizers and pesticides, and if successful the adoption could hurt sales of inputs.

e. Notion that traditional systems are backward, and that the only way to develop is to emulate systems and use technology currently popular in more advanced countries.

22. Opportunities for Intercropping. As described by Andrews (1986), there are a number of ways to improve labor effiency with intercropping, and to increase return to family labor. Also, there are a number of available technologies developed for sole cropping which can be screened and broadly tested for their applicability to more complex systems. From a policy standpoint, an increased emphasis on intercropping would do the following:

a. Build on indigenous technology and resources, and provide viable opportunities for farm families to improve their income and nutrition.

b. Provide a channel for new technologies and the products of scientific research to be incorporated into existing systems, a far more viable option than trying to completely change crops and systems.

c. Increase the productivity of labor by improving labor-intensive intercropping systems to better utilize that labor for income generation, thus making rural life more economically viable and reducing potential for migration to cities — a serious problem in most countries in Africa.

d. Increase production and marketable surplus which can better provide food for the urban market, helping to reduce food imports and loss of valuable foreign exchange.

e. Increased basic food availability, since intercropping often involves basic subsistence crops rather than commercial export crops.

f. Improve the credibility of governments and their agricultural agencies, many of which are not respected in rural areas because of the lack of relevance of current programs.

23. Cautions about Intercropping. This type of system is not a panacea, and a government of development project should not expect that concentration of all efforts in this one area will automatically assure success in agriculture. Systems are complex, as discussed by Andrews (1986), and there are many details to be worked out. Among the most important cautions are:

a. Researchers and extension specialists should be cautious about rushing in with recommendations based on systems which have worked in other regions; these prior results can give good indications of what will work, but the recommendations need to be validated under current conditions.

b. Most technicians will see increased research on intercropping as a threat or challenge to funding and traditional emphasis on sole crops and systems; it is important to describe the benefits that this new dimension will have on all crop production, and how it will enhance the potential impact of a breeding program on each crop.

c. Methods of working with farmers have not been well established in many programs (eg. current difficulty with the institutionalization of Farming Systems Research in the programs of the Ministry of Agriculture in Botswana); these shortcomings need to be overcome, and viable collaborative arangements sought within each culture and economic stratum.

d. Intercropping is no panacea, and will not bring rapid increases in production and reductions in risk with a quick change in policy.

24. Issues in Research and Extension. Most of the issues for modification of the current researh and extension agenda have been mentioned in previous sections. These can be summarized as follows:

a. Greater emphasis needs to be placed on study of complex systems and how crops and animals interact on the farm, including the systems called intercropping.

b. This research should be conducted under the same resource constraints faced by the low-resource farmer, so that results will be credible; much of this work could be done on farm.

c. Additional research methodology is needed to allow efficient study of a number of factors in complex systems; traditional designs and statistical analysis provide some guidelines, but may need modification for proper use.

d. Recommendations on appropriate technology for complex systems, including intercropping, need to be included in the options offered by extension agents who work with low-resource farmers.

e. Women should be involved in the research and extension activities as quickly and extensively as possible; it may be more easy for them to understand the role of women farmers in some cultures, and certainly be easier for them to communicate in extension activities in most cultures.

25. Issues in Education and Training. Intercropping rarely finds its way into the curricula of today's agriculture classes, nor into the training program for para-professionals. This reflects the lack of information and teaching materials, as well as a lack of emphasis in the area of complex systems. What is needed is:

a. Development of teaching and training materials on intercropping and other aspects of low-resource agriculture, including textbooks, practical field exercises, and demonstration materials for use in extension.

b. Management decisions by administrators to include emphasis on intercropping and efficient use of internal resources within the curriculum.

c. Continued practical experience for young technicians, an increasing number of whom come from urban settings where actual farming experience is limited.

d. Training of existing extension agents and orientation of research personnel in these systems which were likely not a part of their formal training in the past; refresher courses and workshops, in-service training, and specific field projects could be used in this effort.

26. Project Assistance and Program Aid. It is a real challenge to incorporate components of intercropping into existing contracts and on-going field programs, when likely none of the development specialists have previous experience in these areas. The potential for influencing the agendas of current projects is less than for new ones coming on stream, although both issues need to be addressed.

a. Develop a series of workshops and materials for people in the field, in an attempt to orient current project managers and technicians about the importance and potentials of intercropping.

b. Similar materials need to be developed and used as related to the exploitation of resources internal to the farm, and the subsequent reduction in use of external production inputs.

c. These orientation materials should be made available to bidders for future development assistance contracts, and the importance of low-resource approaches be written into contracts where appropriate.

d. Develop orientation materials and background documents for decision makers in universities, ministries of agriculture, PVO's and NGO's which describe intercropping, alley cropping, and other innovative systems which can help increase food production. These can be used effectively to influence policy makers, both in the U.S. system and in host governments. Creative methods should be used to include visual and written materials, videotapes, slide shows, and other approaches with a high potential impact.

26a. Current Research and Funding for Intercropping. It is difficult to quantify the current research efforts, although some obvious generalizations are possible. Present research reflects the bias and training of scientists who have moved into decision-making positions during the past 35 years or so. Emphasis is on a single approach to development — a paradigm based on mechanization, inexpensive fossil fuels and their agricultural input derivatives, and economies of scale which favor larger farms and greater productivity per unit of labor. For reasons already described, this paradigm should be challenged. Some scientists have recently put emphasis on intercropping and other complex systems — the international centers in Nigeria (IITA), Kenya (ICRAF), and outreach programs of ICRISAT have become increasingly involved in alley cropping, mixtures of cereals and legumes, and testing varieties for adaptation to these systems. Key scientists in a few national programs (Botswana, Nigeria, Tanzania are known to the author) have emphasized work on intercropping, but they are far in the minority to date. Likewise, counterparts in the U.S. are rarely involved in this type of research, since most researchers see limited application of intercropping in temperate-zone systems. Most African students who leave their countries for advanced training have little chance to study intercropping as an option for improving their agriculture. There is a much greater need for appropriate formal study and field experience with the systems which currently feed much of the population of sub-Saharan Africa.

26b. Balance of Intercropping and Sole Cropping Research. By nature of intercropping, much of the technology developed will be specific to combinations of crops tested and to local resources. This information is less likely to be useful in another situation or with other crops than similar inputs needed to 'dominate' the production environment. A new rice variety for flooded conditions and the accompanying management package (fertilizer, herbicide, insecticide) — such as the high-yielding, semi-dwarf variety IR-36 now grown on millions of hectares — is an easy technology to understand, transplant, and use to advantage if the resources are available. Such research and extension of existing high-tech solutions are important where appropriate. There is a clear need for reserach administrators to achieve a balance between funding for sole crop actibvities and for intercropping — the near total absence of support for the latter over recent decades makes obvious the need for greater emphasis at this time on intercropping.

POTENTIALS OF INTERCROP SYSTEMS

27. Gains from Improvement of Intercropping. As discussed above, the change in emphasis to more work on intercropping will not immediately solve production problems, nor will research and extension concentration on low-resource systems bring higher production levels without a long and concentrated effort in this area. Gains will be small and incremental, but there is a much greater probability of success when programs concentrate on solving production constraints within the context of the resource level on the farm. Realistic approaches to improving existing cropping systems, building on traditional knowledge, and introducing those components of new technology which fit the system can have an impact — where complete transformation of systems often has failed in the past. It is important to consider these technologies in the context of the resource base in which they will be used, and to measure success against past progress with single crops and unrealistic recommendations.

28. Cutting Edge Research on Intercropping. Several areas have been mentioned as needing more attention to improve the potentials of intercrop systems. Among the research needs are:

a. Development of better statistical designs and methods of analysis to handle more than one species, and to allow comparison of production and net return from complex systems.

b. Research methodologies for studying below-ground competition for nutrients and water, and the means to simulate how systems work and make most efficient use of scarce resources.

c. Studies on inter-specific and intra-specific competition for scarce water and nutrients, especially in low-resource farming conditions.

d. Research on nutrient cycling and the effects of rotations and complex crop mixtures on efficient nutrient use; the questions of possible cross-feeding between cereals and legumes and the allelopathic effects of crops on succeeding species require more emphasis.

e. On-farm research methodologies need to be developed to allow a closer collaboration between researcher, extension specialist, and farmer; using farming systems research methodology, more progress can be made than when this work is carried out in isolation by individuals. Although no precise estimates of current research expenditures in this area are available, perhaps ten percent of the international center budgets is invested in the basic research outlined, competition for nutrients and moisture, nutrient cycling, and on-farm research methods. These studies are often not directed at intercropping, but rather at monoculture approaches because of the crop-specific organization of the centers. There is very little in progress in the other areas outlined, and much work is needed on the cutting edge of intercropping research.

29. Use of High Technology Methods. Most of the tools needed to advance work on intercropping are already in the hands of current research and extension specialists. What is needed is a shift in priorities, a change in agenda, to focus more on traditional systems and the potentials of low-resource farms. This approach could be called an information-intensive, a communication-intensive, or a management-intensive alternative to agricultural development. The approach is contrasted to systems which are fossil-fuel intensive, and rely on a domination or modification of the production environment for success. Although some of the processes needed have been conceptualized (Francis et al., 1986) and a number of tools are available to the researcher (Francis, 1986; Gomez and Gomez, 1983), much greater attention is needed in the development of low-cost, practical research approaches which can be used by national programs and by the international centers. The systems which build on internal resources, and minimize the use of external purchased inputs, are in essence substituting information and management skills for expensive inputs. Although based on traditional systems such as intercropping, this is a highly sophisticated approach to farming. It will require well-trained and properly oriented people to implement, and the need for additional training of both farmers and research/extension specialists is vital. Realizing the potentials of intercropping will require a team effort, and the support of

decision makers is critical as well. The key to progress in Africa is to recognize the range of conditions which exist, and to develop options for farmers at many economic levels and with different resource endowments. This will allow the adoption of appropriate new technologies at every level in the spectrum.

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Responses to Reviewer's Comments on:

Challenges of Intercropping: Policy Issues"

1. reviewer is correct in pointing out that this should not be merely a part of "short-term solutions" — the text has been revised in para. 6 accordingly. The further suggestion about animal traction is confusing, since there is no mention of this in either para 6 or para 15. No response or change was made.

2. an example of the early bean/maize research in Colombia is cited to document this statement.

3. this is difficult to estimate — my guess on the proportion of research on systems and intercropping comes from a general perusal of the staff lists of the centers, noting how many people are assigned to their "farming systems" or "multiple cropping" programs. The revised text explains how preliminary these estimates are, and these may not be as well researched as the numbers noted in Wolf's excellent review.

4. this 10% was pulled out of the air, although it does reflect visits and correspondence with a number of the key actors in AID financed projects. As the revised text suggests, this is a most subjective estimate, but one that could be fine-tuned through survey or other communication with key AID people.

5. insert information as suggested by the reviewer: "This has not happened in most areas, and we need to find ways to improve the systems. This process is complicated because many of our traditional approaches have not worked — mechanization and chemical weed control are difficult because of the multiple species of crops, soil fertility is more complex due to multiple needs of crops, relative priorities for insect/pathogen resistance versus other traits are different from monoculture. In summary, the constraints are different."

6. detail is not needed here, as the paper is already over the prescribed length; readers may find more detail in Harwood's two references. The sentence is rewritten.

7. insert this example: "In the Cauca Valley of Colombia, the extension service has recommended replacing the multiple cropped parcels with maize and soybeans, two well-adapted commercial crops in the zone. The new monocrops require purchased fertilizers and insecticides, mechanization, and other costly inputs for which the farmer needs credit. If successful, harvest comes two times per year, and the family must manage the income from harvest to buy food during the next four to seven months. Although net income would appear

to be greater from this system, there are new risks with credit and inability to manage funds over a period of time. In contrast, the traditional system provides a series of basic foods (maize, cassava, beans, banana, papaya, pineapple, and others) as well as products for sale (coffee, cacao, some excess of the other crops) which can sustain the family well through the entire year."

8. insert: "The most important policy issue is the recognition that traditional systems are very much a part of the total culture and often well-suited to available internal resources — massive programs to "modernize" these systems must be carefully tailored to both people's goals and educational levels, and to the natural resource base."

9. more specifics are inserted in the text.

10. insert: "Many scientists argue that on-farm research is costly, high-risk, and without control over experimental variables. Although all these arguments are valid, we sometimes maintain a bias toward station research because of lack of courage, experience, and appreciation of the vital need to work under the same constraints which face the farmer. Much greater emphasis is needed on FSR and on-farm research/extension activities, with station research reserved for only those specialized activities which cannot be done elsewhere."

11. clarification of "c": increase the productivity of labor by improving labor-intensive intercropping systems to better utilize that labor for income generation, thus making rural life more economically viable and reducing potential for migration to cities — a serious problem in most countries of Africa.

12. insert at end of paragraph: "Although no precise estimates of current research expenditures in this area are available, perhaps ten percent of the international center budgets is invested in the basic research outlined -- competition for nutrients and moisture, nutrient cycling, and on-farm research methods. These studies are often not directed at intercropping, but rather at monoculture approaches because of the crop-specific organization of the centers. There is very little in progress in the other areas outlined, and much work is needed on the cutting edge of intercropping research."

13. insert: "Although some of the processes needed have been conceptualized (Francis et al., 1986) and a number of tools are available to the researcher (Francis, 1986; Gomez and Gomez, 1983), much greater attention is needed in the development of low-cost, practical research approaches which can be used by national programs and by the international centers."

14. insert: another paragraph (26a) is needed, following the paragraph 26 "Project Assistance and Program Aid", which relates to current research and training — there is no data on specific investments, and it is difficult to say anything much mroe quantitative than what is here:

"26a. Current Research and Funding for Intercropping. It is difficult to quantify the current research effort, although some obvious generalizations are possible. Present research reflects the bias and training of scientists who have moved into decision-making positions during the past 35 years or so. Emphasis is on a single approach to development — a paradigm based on mechanization, inexpensive fossil fuels and their agricultural input derivatives, and economies of scale which favor larger farms and greater productivity per unit of labor. For reasons already described, this paradigm should be challenged. Some scientists have recently put emphasis on intercropping and other complex systems — the international centers in Nigeria (IITA), Kenya (ICRAF), and outreach programs of ICRISAT have become increasingly involved in alley cropping, mixtures of cereals and legumes, and testing varieties for adaptation to these systems. Key scientists in a few national programs (Botswana, Nigeria, Tanzania are known to the author) have emphasized work on intercropping, but they are far in the minority to date. Likewise, counterparts in the U.S. are rarely involved in this type of research, since most researchers see limited application of intercropping in temperate-zone systems. Most African students who leave their countries for advanced training have little chance to study intercropping as an option for improving their agriculture. There is a much greater need for appropriate formal study and field experience with the systems which currently feed much of the population of sub-Saharan Africa."

15. The statement in paragraph 2 may be overdrawn and/or overstated -- I only wish that it were dated! In traveling in Africa and reviewing current research and extension projects, I find that most people are still operating very much under the paradigm described here. Sorry that it's still that way -- perhaps your report can help to improve the situation. Intercropping is just a small sub-set of this larger challenge.

16. Fully agree with the reviewer -- I hope that this balance can be brought into your final document, as well as the discussions about marketing and urban potentials.

17. These two comments by the reviewer are excellent, and help to bring perspective to the paper. An additional paragraph is added.

"26b. Balance of Intercropping and Sole Cropping Research. By nature of intercropping, much of the technology developed will be specific to combinations of crops tested and to local resources. This information is less likely to be useful in another situation or with other crops than similar recommendations developed for a sole crop -- with all the inputs needed to 'dominate' the production environment. A new rice variety for flooded conditions and the accompanying management package (fertilizer, herbicide, insecticide) -- such as the high-yielding, semi-dwarf variety IR-36 now grown on millions of hectares-- is an easy technology to understand, transplant, and use to advantage if the resources are available. Such research and extension of existing high-tech solutions are important where appropriate. There is a clear need for research administrators to achieve a balance between funding for sole crop activities and for intercropping -- the near total absence of support for the latter over recent decades makes obvious the need for greater emphasis at this time on intercropping."

18. with all due respect to my long-time friend and colleague, I think that OTA publications are right on target. At times it is necessary to overstate a case in order to wake people up -- but it's also critical to have the courage to look into the future, and not be over-awed by what has worked in the past and in other places. I think that OTA does a good job of this. The "high levels of investment in the research systems" do need to be maintained, but that does not mean that all this research has to be done on atypical experiment stations! I think that some of his concerns have been addressed in other revisions already noted above.

19. If there is any prevalent "party line" in development, it revolves around high technology and fossil fuel inputs -- hard to buy this argument about our descriptions of the potentials of intercropping. The "higher level of management" is an excellent point, and a sentence is added to para. 15 to emphasize this.

20. I think that we have adequately addressed the risk issue, at least in a qualitative way.

21. Site-specificity and the balance of resources needed in sole cropping vs. intercropping research has been discussed -- probably not to anyone's satisfaction due to lack of data on this.

22. We have not talked at all about intensive urban gardens, in either this paper or the one by Andrews -- perhaps this is a serious void which should be addressed by another paper, or by some long phone calls or telex

communication with AVRDC or the Farming Systems people in IITA?

23. There is no doubt about our lack of communication. If we examine the recent review of multiple cropping (Francis, 1986), however, there are two chapters written by authors in the U.K. and heavy referencing to the pioneering work done by such scientists as Bob Willey (ICRISAT, now at East Anglia), Roger Mead, and others with well-established reputations in this area.

FINAL DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

AGROFORESTRY IN AFRICA

by

Roy T. Hagen

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January 1987

FINAL DRAFT

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1. EXECUTIVE SUMMARY

1.1 Agroforestry farming techniques are those in which trees or shrubs are deliberately grown with agricultural crops or livestock either simultaneously or consecutively. Trees have the ability to improve soil productivity and to increase crop yields while simulutaneously producing firewood and other wood products, edible fruits, seeds and leaves, fodder, fiber, traditional medicines, etc. Agroforestry techniques are generally low input, environmentally sound practices which contribute to more diversified, lower risk production systems. Agroforestry practices include intercropping with dispersed field trees, alley cropping, windbreaks, live fencing and others. Acacia albida intercropping, alley cropping and windbreaks have all been documented to significantly increase agricultural crop yields.

1.2. Many modern, temperate zone farming practices are not suited to tropical conditions and lead to declining soil fertility and accelerated erosion. Although most African farming systems use traditional agroforestry techniques, especially intercropping, nearly all traditional techniques can be improved on. Other, more modern agroforestry techniques, such as windbreaks and alley cropping, have been very successful locally in pilot projects or in station trials, but are not at all widespread in Africa. Alley cropping has demonstrated the technical feasibility of permanent cropping in the humid tropics without the use of chemical fertilizer.

1.3 Agroforestry is certainly not a cure-all for agricultural development. It must be viewed as an element of the farming systems of low resource agriculturalist. Traditional systems and indigenous technical knowledge can form a good base on which to develop improved techniques.

1.4 The development of agroforestry will require a truly interdisciplinary approach overcoming the traditional segregation of the disciplines of agronomy, forestry and range/livestock mangagement. Although our knowledge of agroforestry systems is very incomplete, we have enough data and enough successful model interventions on which to base a greatly expanded agroforestry development program for Africa. Agroforestry development on communal lands and on leased or borrowed lands will be limited. PVOs have the best track record in agroforestry development.

1.5 Agroforestry has the potential to partially resolve two of the most difficult problems in sub-Saharan Africa today--desertification of the semi-arid zones and the widespread, declining crop yields. The low risk and low material input nature of agroforestry techniques makes them well suited for low-resource agriculturalists in Africa. Given the small investment in agroforestry development to date, one could expect significant advances in the science and and in the adoption of agroforestry if more resources were dedicated to this sector.

1.6 Applied correctly, agroforestry can significantly improve crop yields for low-resource farmers in tropical Africa while simultaneously producing wood and other secondary products and services in an environmentally sound and stable manner.

"One thing is certain--the following message must be communicated to well-meaning foreign aid bureaus of northern countries: temperate-zone agro-technology cannot be transferred unmodified to tropical regions."..
Fundamentals of Ecology, Odum, 1971

2.1 Agroforestry is the term used to describe a wide range of farming techniques in which trees and/or shrubs are deliberately grown in association with agricultural crops and/or with livestock, either simultaneously or sequentially through time. While the term "agroforestry" has only recently been coined, many agroforestry techniques have been practiced for generations. Indeed, trees and shrubs are an integral part of most traditional African farming systems; In most of sub-Saharan Africa, cleared treeless fields so characteristic of temperate zones are the exception rather than the rule.

2.2 Soil fertility maintenance and water availability during the cropping season are probably the two most important constraints to African agriculture. The physical basis of agroforestry depends primarily on the ability of trees to improve and maintain soil fertility and their ability to increase water availability for crops.

2.3 Of the different soil properties which influence crop yields, one of the most important, and probably the factor most susceptible to manipulation by low-resource agriculturalists, is soil organic matter. Soil organic matter breaks down much more rapidly under a tropical climate because of the continuously high temperatures. Average soil organic matter and nitrogen generally decrease by one half to two thirds for each 10 degree Centigrade increase in average annual temperature (Buckman and Brady, 1968). Soil organic matter under certain field trees can be more than double that of the soil away from the trees (Nair, 1984; Felker, 1978). Trees can also improve soil fertility by recycling nutrients which have been leached into the subsoil beyond the reach of shallow rooted crops. Nitrogen fixing trees are especially important in improving soil fertility both because tropical crop soils are commonly deficient in nitrogen, and because the amount on nitrogen available seems to directly affect the level of organic matter maintenance in the soil (Brady and Buckman, 1968).

2.4 Trees can increase the amount of water available for crop growth in the following ways:

-decreased water loss through evapotranspiration due to their windbreak action in decreasing near-surface windspeeds,

-through increased infiltration of rainwater due to improved soil physical properties.

-through increased retention of soil moisture due to higher levels of soil organic matter.

-through decreased soil temperatures due to shading (Weber, 1986)

2.5 Agroforestry systems permit the simultaneous production of agricultural crops along with a variety of the following wood and secondary products and services:

-firewood and charcoal
-posts, poles and construction wood
-fruit, edible leaves and seed, etc.
-fodder
-fiber for mats, baskets, rope, etc.
-plant materials for medicines, dyes, cosmetics, tannins, glue, etc.
-shade
-reduced water and wind erosion

2.6 Agroforestry practices may be classified in many ways; the following is a simple, generalized outline of common techniques:

2.7 -Dispersed Field-Tree Intercropping. Single, open grown trees are dispersed throughout a farm field or garden. When natural regeneration is relied upon, the trees appear to have a random arrangement. The farm/parklands of semiarid West Africa typify this traditional technique. Planted trees are usually aligned in rows at regular intervals. Orchards and tree crops such as oil palm and cacao are often intercropped.

2.8 -Alley Cropping. A technique recently developed by the International Institute of Tropical Agriculture in the humid tropics. Agricultural crops are raised in narrow two to four meter "alleys" between hedges of deep-rooted trees or shrubs which are pruned several times during the growing season with most of the clippings returned to enrich the soil.

2.9 -Windbreaks (also called shelterbelts). Continuous, uniform rows of trees planted perpendicular to the prevailing winds to reduce water loss from crop fields and/or to reduce wind erosion.

2.10 -Live Fencing. Trees and shrubs or other perennials are cultured to form an impenetrable living fence around a field or garden. Or, trees may be planted as live posts for a fence.

2.11 -Other Linear Plantings. Trees and shrubs are often grown along field margins to demarcate the borders. Woody plants are also commonly used in soil and water conservation practices on sloping fields with contour strips of vegetation or on contour ridges. Linear plantings along trails, roads, streamsides, etc., may or may not be agroforestry plantings depending on the situation.

2.12 It is commonly assumed that trees grown in close association with agricultural crops will compete with the crops causing a decrease in crop yields. While this is sometimes true, trees can complement, supplement or compete with agricultural crops (Raintree, 1982). These relationships are distinguished as follows:

2.13 -A complementary relationship exists if the tree-crop association leads to an actual increase in crop yields. The classic example of this is the traditional intercropping of Acacia albida with millet, sorghum or groundnuts. Millet and groundnut yields of 500 kg/ha on infertile soils can be expected to increase to about 900 kg/ha under a canopy of the Nitrogen fixing Acacia albida (Felker, 1978). A second example of a complementary relationship comes from CARE's Majjia Valley Windbreak Project in Niger. Fields protected by neem (Azadirachta indica) windbreaks had millet yields averaging 15% more than fields not protected by windbreaks (Dennison, 1985). (This yield increase does not include the land occupied by the windbreak itself which is not cropped. A third documented example of a complementary relationship comes from IITA station trials of alley cropping at Ibadan, Nigeria in the humid tropics. Yields of maize stabilized at about 2 tons/ha after 6 years of continuous alley cropping compared to less than one half ton/ha yield without alley cropping (Kang, et al, 1984)

2.14 -A supplementary relationship exists if the tree component has no significant effect on crop yields. An example of this is the intercropping of tall, widely spaced coconuts over farm crops.

2.15 -A competitive relationship exists if the addition of the tree component leads to a decrease in agricultural yields. It is important to realize, however, that even though crop yields may be somewhat diminished, the overall economic or socioeconomic benefits of the agroforestry practice may be positive.

3. THE STATUS OF AGROFORESTRY

3.1a Shifting agriculture.

The widespread practice of shifting agriculture on upland rainfed sites in tropical Africa is due to a basic difrerence in the pattern of nutrient cycling between the tropics and the temperate zones. In temperate zones a large portion of the organic matter and the available nutrients necessary for plant growth are typically found in the soil. In the tropics a much larger percentage is found in the living biomass and is recycled within the organic structure of the system. (Odum, 1971) When the vegetation is cleared for a new field, the nutrients in the biomass are released through fire or decomposition. Furthermore, the soil organic matter, which could absorb much of these nutrients, itself breaks down under cultivation and continuously high temperatures. The nutrients are then leached out by rainfall, productivity drops rapidly, and the field is abandonned after a few years.

3.1b Shifting agriculture with bush fallow is itself an agroforestry system which has been practiced for centuries. Fields are cropped for several years followed by an extended woody fallow with deep-rooted trees and shrubs playing a key role in the restoration of soil fertility. In the past, with low population levels and land freely available, shifting agriculture was a biologically sound system of subsistence agriculture. Fields were typically cropped for 5 to 7 years in the semiarid zones and from 1 to 3 years in the high rainfall humid zones. The cropping cycle was then followed by up to 20 or 30 years of bush fallow. (From author's personal experience in discussion with African farmers and resource professionals and confirmed by Fred Weber who also stated that an FAO publication called "Shifting Agriculture" will back up this statement.)

3.2 Today there are few remaining areas where the population/land balance permits land to be fallowed for 20 or 30 years. When land becomes scarce, the result is usually a shortened fallow period which in turn results in decreased per hectare yields. This is turn results in more marginal lands put into production or in more hectares per family cropped to make up for the lower yields. In some areas. average per hectare yields have been declining for 20 years. Although still practiced with a shortened fallow period, shifting agriculture is no longer a viable agroforestry system over much of Africa

3.3 Dispersed Field Tree Intercropping.

After shifting agriculture, dispersed field tree intercropping is the most widely practiced general agroforestry technique in Africa. Both within and between agroecological zones, specific intercropping practices vary greatly with thousands of variations as to the tree/crop species mixtures, the spacing, crown coverage and spatial arrangement of the trees, and as to the products and benefits derived from the trees.

3.4 In semi-arid regions, particularly in West Africa, the vast majority of low-resource agriculturalists practice intercropping on their rainfed upland fields, although trees and not commonly planted on these fields. When clearing the bush for a new field, certain species are preserved. These are most commonly food producing trees (fruits, nuts, leaves, etc.) such as the shea tree (Butyrospermum parkii) or the locust bean (Parkia biglobosa). Such savanna species, however, often to do not regenerate well naturally under field conditions.

3.5 The Acacia albida is an exceptional and very unique tree species traditionally intercropped with millet and sorghum in semi-arid regions. The most unique feature of this nitrogen-fixing tree is that it loses its leaves during the rainy season making it possible to raise crops directly under the canopy of the tree with no real competition for light. The Acacia albida is not common in the natural bush but slowly increases over time in farm fields due to the protection afforded the seedlings by farmers. The main benefits of the tree are the much higher crops yields under the tree and the rich animal feed from its pods and leaves.

3.6 Natural regeneration is erratic, however, and in areas recently cleared for farming there may be little or no Acacia albida. Even on old fields where the tree is common, the tree cover is often far below that which would give optimum yields. Extended drought and grazing pressures have also reduced the natural regeneration of this tree.

3.7 In the more humid zones, intercropping is more commonly practiced on smaller, intensively managed and continuously cropped home gardens, usually within the family compound. These systems are often very complex and have generally received very little attention from research or development organizations. Intercropping is also commonly practiced in association with a variety of tree cash crops such as oil palm, coconuts, cacao, and rubber trees. These trees are usually planted at a fixed, regular spacing. Intercropping with these tree crops is done both on a large commercial scale and also commonly by smallholders.

3.8 Alley Cropping.

Alley cropping is a modern agroforestry technique that has only recently been developed. Most of the work was done at the field laboratories of IITA in Nigeria. On farm trials have only recently begun in a few countries. At present there are probably not any smallholders who are practicing this technique on their own.

3.9 The exciting thing about alley cropping is that it represents a ecologically sound, stable alternative to shifting agriculture in the humid tropics. The scientists at IITA worked to incorporate the good features of the bush fallow into a continuously productive farming system. This approach of building on a traditional system using modern scientific methods has been used far too infrequently in the tropics.

3.10 However, alley cropping with closely spaced woody hedges at 2 to 4 meter intervals represents a radical change in farming practices for the smallholder. As on-farm trials are only beginning, and the extension of alley cropping has not really begun, it is too early to judge how successful the technique will prove, how rapid will be its acceptance rate by smallholders, or what modifications may prove necessary to assure its acceptance.

3.11 Windbreaks.

The author knows of no traditional uses of windbreaks in sub-Saharan Africa. Their use is not widespread, and in many areas the technique is unknown to the local farmers. Windbreaks are most appropriate in arid and semi-arid zones where water is commonly a limiting factor to crop production and/or where wind erosion is a problem.

3.12 There has been one highly successful windbreak project, the Majjia Valley Windbreak Project in Niger which is often touted as one of the most successful forestry projects in the Sahel. Begun in 1975 with the assistance of CARE, the project has established about 350 kilometers of windbreaks which protect over 3000 has. of rainfed millet and sorghum fields (CARE, 1986). Wind erosion was major problem in the Valley, but has been largely controlled where windbreaks have been established. Average crop yields on the fields between the windbreaks have increased by about 15% (Dennison, 1985). At the same time, periodic partial harvesting of the windbreaks should make the participating villages largely self sufficient for their wood needs (Heermans, pers. comm., 1985). The ownership of the windbreaks and the distribution of wood products to be harvested from them have not been resolved.

3.13 The small average field size and the need to orient the windbreaks perpendicular to the prevailing winds makes it impractical for the individual smallholder to establish windbreaks on his own. To be successful, a group of farmers, ideally an entire village as was done in the Majjia, must cooperate in the effort so that windbreaks may cut across adjoining fields.

3.14 Another constraint in windbreak establishment is the protection required against livestock. In semi-arid regions, livestock are ususally left to run free during the dry season; they are not fenced or herded. Block plantations are relatively easy to protect with fences, but windbreaks or other field plantings which are dispersed over large areas pose a more difficult problem. In the Majjia, the villagers agreed not to allow grazing during the approximately three years required for the trees to grow out of the reach of livestock. This was enforced with guardians hired with project funds.

3.15 The Majjia Valley project started out in response to a request for assistance from local villages. It began on a small scale working closely with forest service agents and villagers. The project has developed enthusiastic support from villagers as yields have increased, and is now receiving numerous requests for assistance from surrounding villages.

3.16 Live Fences.

The use of live fencing varies greatly between regions. In some places it is almost unknown; in the Fouta Djalon Highlands in Guinea there is a social caste (like blacksmiths) who make their living establishing live fences.

3.17 The purchase of metal fencing is usually beyond the means of the low-resource agriculturalist. Although they can be labor intensive to establish, live fences provide a low cost alternative to metal fencing. In semi-arid regions fences used to be made with readily available thorn bushes. With desertification and increased demands on resources, thornbushes are often in increasingly scarce supply. Here live fencing could be very advantageous, especially around dry season gardens which must be protected from free ranging livestock. Unfamiliarity with live fencing techniques appears to be a significant constraint in many areas.

3.18 Live fences require a large number of closely spaced plants and frequent pruning and care to be effective. Species which can be direct seeded or started from cuttings are much preferred. Some successful live fencing species such as sisal and certain succulents are non-woody.

3.19There appears to have been relatively little work done with live fencing by the major development agencies.

3.20 Other Linear Plantings.

Farmers often leave at least partial strips of natural vegetation to mark their field borders. Encouraging the planting of multipurpose trees and shrubs along field margins is often easily achieved as most farmers have a desire to define the limits of their property in a concrete fashion. Field border plantings may serve as a first step towards the extension of more innovative agroforestry techniques.

3.21 Trees can play a major role in soil erosion control measures; their use for this purpose is most common is East Africa. One of the most ambitious, well developed agroforestry projects in Africa, and one with a strong erosion control component, is the German (GTZ) sponsored Projet Agro-Pastoral de Nyabisindu in the densely populated highlands in Rwanda (Projet Agro Pastoral de Nyabisindu, no date; Behmel et al, no date). Since 1976, the goal of the project has been the development of an ecologically sound farming system for the region which has been strongly affected by erosion, soil degradation, deforestation, etc. Initial efforts focused on high input modern methods using high-yield varieties, chemical fertilizers and pesticides. These attempts were totally unsuccessful and were abandonned.

3.22 At this point the project began a study of the indigenous farming systems of East Africa on which to build an appropriate strategy for Rwanda. This approach has been far more productive and is leading to an intimate integration of trees with agriculture and animal husbandry. Millions of multipurpose tree seedlings are produced annually for planting on vegetation strips and contour ridges, for roadside and compound plantings, for dispersed field tree plantings and for reforestation of badly degraded sites unsuitable for agriculture. The project has also gone a long ways in developing appropriate cultural techniques including methods of root and branch pruning to enhance crop yields.

3.23 General Status of Agroforestry in Africa.

Although most traditional African farming systems incorporate agroforestry techniques, it is only very recently that most development assistance agencies have become interested. Most development aid has gone towards attempting to apply modern, temperate zone, high-input agricultural techniques. Most of these attempts have failed, especially for the low-resource agriculturalist. Conditions in the tropics are markedly different from the temeperate zones, and require different approaches.

3.24 There are only a few development projects which have been working with agroforestry for as long as 10 years. Most of these few have made substantial progress towards developing stable, sustainable farming systems. It is the author's opinion that development agencies have only scratched the surface of agroforestry's potential for improving the lot of the low-resource agriculturalist in Africa.

Table 1. Application of OTA's Principles and Concepts

Needs	How to do it	Who should do it	Limits
Principle A: Systems Approach			
-Better programming of agroforestry projects	-multidisciplinary teams	-development agencies	-segregation of disciplines
Principle B: Linkages			
-Identify supporting resources, institutions and individuals -develop means of support	-reconnaissance surveys	-extension agents -project personnel	-poor data
Principle C: Minimizing Risk/Maximizing Returns			
-Develop diversified production systems	-Maximize variety of tree/crop/livestock mixes	-agronomists, range mgrs., and foresters working with farmers	-lack of communication
Principle D: Local Resources			
-Describe traditional agroforestry practices in proj. area and in region. -Catalog uses of local species	-reconnaisance surveys -sociological studies	-national research centers -universities -PCVs	-funds and transport -
Principle E: Heterogeneity			
-Develop range of strategies and technologies	-professionals interacting with low-resource agriculturalists		-complexity -lack of appreciation of diversity
Principle F: Role of Women			
-Determine sex differences for fuelwood gathering, tree planting, tree care, tree tenure, decision making	-reconnaissance surveys -sociological studies	-IARCs -universities	-limited number of women in agr.
Increase input from women	-train and use more women for extension		
Principle G: Sustainability			
-Analyze traditional and improved or modern systems for sustainability	-economic analyses -monitor soil fertility & erosion	-consultants -universities	-climatic fluctuations -Short term outlook

Principle H: Local participation

-Include local participation at all stages of project dvlpt.	-Mandate	-development agencies	-traditionally ignored

5 KEY SHORT AND LONG TERM POLICY ISSUES RELATING TO AGROFORESTRY IN AFRICA

5.1 The following is a list of some of the policy issues related to agroforestry development in Africa:

-a. The professional training and experience of western resource specialists impedes agroforestry development.

-b. The segregation and lack of coordination between the agriculture, forestry and livestock services of many African governments has impeded agroforestry development.

-c. The lack of schools of agroforestry or even of courses in agroforestry may impede agroforestry development.

-d. Given the primitive state of knowledge on agroforestry in Africa, is it best to undertake an extended period of basic research before implementing actual development projects?

-e.. Will land tenure constraints and tree-benefit-rights severely limit agroforestry development?

-f. Although ecologically sound, agroforestry may only mean an increased burden for the already overworked African woman.

-g. What type(s) of development agencies (major donors, PVOs, universities, etc.) are best suited for agroforestry development?

-h. Given the demographic rate of population growth in most African countries, can agroforestry really improve the lot of the African smallholder, or is it only a stop-gap measure?

-i. The paramilitary nature of many African forest services and their policing functions will make it very difficult for them to be effective agroforestry extension agents.

-j. Trees take so long to grow that farmers faced with much more immediate survival needs will have little interest in tree planting unless paid to do so.

-k. Will planting trees in farmers' fields result in increased depradation by crop eating birds such as the weaver bird, Quelea quelea?

-l. Won't trees planted in farmers' fields negate the possibility of eventually mechanizing farm operations?

-m. Given the complexity of multiple component agroforestry systems compared to conventional temperate zone monocropping, are conventional economic analyses adequate for developing and selecting the optimal agroforestry techniques for a given area?

-n Would the widespread intensive use of dispersed field trees such as Acacia albida in semi-arid zones result in a lowered water table only substituting one hardship for another?

5.2 A discussion of policy issues a. through h. and j., which are deemed to be of particular importance to Congress, follows:

a. The background of western resource specialists seems to have played a major role in retarding interest in the potential of agroforestry in African development. In Africa, agricultural activities, livestock production and use and management of trees for domestic use commonly take place on the same piece of ground either simultaneously or consecutively through time. In the U.S. and Europe, these production activities are usually strongly segregated on different land areas. Agronomy, range management and forestry are likewise distinct disciplines. The relative nutrient cycling capabilities of different tree species and the compatibility of trees with different crops mixtures are esoteric topics.

5.5 Most western resource specialists have tried to apply temperate zone techniques to tropical Africa. Agronomists have been trying to repeat the 1960's success of the Green Revolution with high yield hybrids, chemical fertilizers, pesticides and mechanization. Range managers advocated the creation of ranches where livestock production was the exclusive activity. Foresters first concentrated on block plantations, large and small, using introduced exotic species with wood volume/ha/yr as the main criteria for success. An exception to this pattern was the research on the effects of Acacia albida on crop yields done by French agronomists in the 1960s.

5.6 By and large, foresters have been the first to embrace the concept of agroforestry. They have found that low-resource agriculturalists faced with insufficient crop yields will rarely devote land and energies to tree plantations devoted soley to firewood production even though firewood may be so scarce that they have resorted to burning crop residues. However, those few projects such as the Majjia Valley Windbreak Project which have involved tree planting on farmer's fields for the purpose of increasing crop yields have enjoyed much greater success.

To this day, agroforestry conferences and workshops are usually attended primarily by foresters with relatively few agronomists or livestock specialists involved. Agroforestry development will advance very slowly if this does not change. Most development dollars in tropical Africa go for agriculture, and few agronomists have showed much interest in agroforestry. A truly multidisciplinary approach will be necessary if much progress is to be made.

5.8 -b. The agriculture, forestry and livestock services of most African governments are just as strongly segregated as in the U.S. Indeed, this is a direct legacy of the western colonial powers. Such institutionalized differences will not be changed overnight, but increased integration and cooperation between disciplines must be strongly encouraged. Participation of all relevant government services should be negotiated in the project planning stage, even though this may make the project administratively more burdensome.

5.9a -c. The lack of agroforestry schools or of courses in agroforestry, both in Africa and in the West, is once again due to the nature of temperate zone agriculture, the legacy of the colonial powers and to the newness of the discipline. Probably less than a half dozen universities in the U.S. offer instruction in agroforestry, usually a single, recently created course (Frederick Steiner, pers. comm., 1987). Oxford in England and Wageningen in The Netherlands offer courses in agroforestry as part of degree programs in tropical forestry. Most professionals familiar with agroforestry have become so through their own work experiences and contacts, through the growing body of literature or through conferences or workshops on the topic.

5.9b There is a great need for African agronomy, forestry and livestock schools to begin to incorporate agroforestry into their course offerings. Donor agencies should support such curriculum development. Regional agroforestry schools for the different agroecological zones may eventually be appropriate.

5.10 -d. Some have argued that we do not have enough hard data for us to adequately plan and execute agroforestry projects at this point. They would further argue that techniques need to be perfected under the controlled conditions of field research stations followed by on farm trials before moving into an extension mode.

5.11 Research involving trees takes a good deal of time. There are many more variables to quantify in most agroforestry techniques than in simple monocropping. Research conducted at research centers, especially in Africa, often fails to account for the real life conditions of the low-resource agriculturalist. And it is ultimately the smallholder who will accept or reject a practice using his own criteria. Furthermore there is reasonably good data, at least for certain practices such as Acacia albida intercropping and neem windbreaks in the semi-arid zone on which to build. The author feels that development activities and station trials should be conducted simultaneously with the maximum possible exchange of information between development agencies, smallholders and station scientists. Development projects need to be programmed over relatively long time periods, i.e. circa 10 years. Agroforestry projects should start out at a fairly small scale expanding and building on their successes as is merited.

5.12 -e. Farmers will rarely plant, let alone protect and care for trees, if they have no assurance that they will eventually benefit from the trees. In sub-Saharan Africa few smallholders hold title to the property they cultivate. The central governments generally maintain that all land belongs to the government. In practice, however, most farmland is passed down from one generation to another remaining under family control. Women rarely have property rights, even when they supply the bulk of the agricultural labor.

5.13 In some areas, a large percentage of farmland is cultivated by families who have borrowed or leased their fields from families that own land. Such farmers may have little incentive to invest thir energies in planting and caring for trees when they have no guarantee they will be working the same field the following year. Indeed, the landowner may forbid the planting of trees by the tenant if local custom associates tree planting with land tenure rights as is often the case. Land and tree rights are sometimes separate; the rights to harvest products from trees on a field may belong to someone other than the owner of the field. Even where land tenure is well defined, national forestry legislation mey severely restrict the landowner's rights to cut, or even prune branches from, the trees growing on his field. Even when the field trees are planted by the landowner, his cutting rights may be severely restricted (Thomson, 1985) Thirteen years after the start-up of the Majjia Valley Windbreak Project, the Nigerien government still has not decided who the trees in the windbreaks belong to (Dennison, pers. comm., Dec. 1986)

5.14 Communal farmland also exists, although not as commonly as is generally believed. Communal groups are relatively easy to mobilize for tree planting efforts, but the track record of communal tree planting efforts is not good. What belongs to the group is no one individual's responsibility, and the care and protection needed by young trees is too often lacking on communal lands.

5.15a Little can be done in the short term to change local land and tree tenure practices, but they must be understood and accounted for in the design of agroforestry projects. Eventual use rights of trees to be planted with donor assistance should be defined and agreed upon by all parties involved during the design stage of the project. Due to the relatively long term investment required in agroforestry, one should expect the greatest success when working directly with the smallholder who owns his own land. In this respect, agroforestry may differ significantly from the high-input approach to agricultural development. Investments in improved seed, chemical fertilizer and pesticides are short term investments which the farmer tilling leased or borrowed land can hope to benefit from. But agroforestry is essentially a long term investment in the land itself, in improving and assuring its long term productivity. This makes land tenure a much more critical factor.

5.15b An alternative approach might be to subsidize smallholders for tree planting or soil conservation measures. This has been commonly done in the U.S. for several decades. Subsidies are especially appropriate for conservation measures which require a long period of time before benefits are realized; this might include Acacia albida plantings or soil erosion control structures. It is difficult to envision most African governments being able to finance such measures, however, on any significant scale. Mali is currently experimenting with achieving fuelwood conservation through legislation. A law was passed in 1986 requiring every family to have an improved wood cookstove by about February 1987. It remains to be seen how effective this will prove or how it may be enforced; will forestry agents enter into private homes to inspect their cooking areas?

5.15c Food-for-work has been used for tree planting, especially during times of crop failures or food shortages. The main problem is in the precedent established if one is not committed to long term subsidies.

5.16 African governments should be encouraged to reasses their land tenure laws and forestry legislation in view of granting smallholders greater assurance of long term property rights under an equitable system of land tenure.

5.17 -f. The question as to how agroforestry will affect the position of women has no readily apparent answer. In many African societies women do nearly all of the domestic labor (preparing meals, carrying water, gathering firewood, caring for children) and often a large part of the farmwork also. Those agroforestry techniques which are more labor intensive than traditional cropping practices could result in even more work for the women.

5.18 The women should benefit along with the family in general from improved, more reliable and diversified crop yields. If firewood is produced from field trees for domestic use, this could significantly reduce the women's task of gathering wood from communal sources that may be many kilometers from her compound. On the other hand, if firewood from field trees is sold by the men for cash income, as has happened in some village woodlot programs, the women would not benefit directly.

5.19 Where tree planting is associated with land tenure and women are not permitted to own land, women may not be allowed to plant trees. However, as women are generally responsible for firewood gathering, where they do have the possibility of planting trees, they may have a special incentive to plant firewood producing species on sites close to their compounds where firewood is used.

5.20 -g. The larger development agencies such as USAID or the World Bank have generally not been the leaders in agroforestry advances nor have universities. The Netherlands, Switzerland, Germany and Canada have better track records for people-oriented agroforestry development. PVOs, however, see to have the best record both in pioneering some of the first projects and in successful smallholder adoption of the techniques. PVOs typically base their development projects of strong local input and community participation. They d best at small scale development and generally enjoy mu cn greater flexibility t modify their interventions as conditions warrant than do the large scale development projects that are locked into specific project accords.

5.21 CARE in particular has been an innovator in agroforestry. It's windbreak and Acacia albida projects in Niger and Chad are over 10 years old. CARE has 1 agroforestry projects in 11 African countries (Kramer, 1985)

5.22 A frequent weakness of PVOs is their lack of technical expertise and thei unfamiliarity with applied research. Greater collaboration between PVOs and universities or private consulting firms working in development may be a solution to this problem.

5.23 If populations continue to grow at their present rate, then any gains in productivity from agroforestry development will certainly be negated by demographic growth. The U.S. should encourage and support family planning wherever conditions permit.

5.24 -k. In some areas, such as in the lowland rice producing areas in Maritime Guinea near Conakry, crop depradation by birds is very serious. In other areas, such as Care's Koro Village Agroforestry Project area in the Fifth Region of Mali, the problem seems to be negligible. The author is unaware of what factor or combination of factors leads to birds being a major problem on crops. It seems significant that even in severe problem areas such as in Guinea, farmers have not eliminated trees from in or around their fields. Fiel trees provide a vantage point from which birds can survey a field for signs of danger before landing to feed on the crop. Trees are also used for nesting, bu birds can easily travel significant distances from nesting site to field. Woul eliminating field trees reduce crop depradation by birds?

6. THE POTENTIAL OF AGROFORESTRY IN AFRICA

6.1 Agroforestry has the potential to partially resolve two of the most difficult problems facing Africa today--desertification in the semi-arid zones and declining yields from rainfed agricultural crops throughout most of the sub-Saharan region.

Agroforestry and Desertification.

6.2 Drought, overgrazing and overcutting for firewood have all contributed to the problem of desertification, but destructive agricultural practices in the approximately 400 to 700 mm rainfall zone have probably been the most important factor in desertification. The most severe problem is on the agricultural lands of the semi-arid zone, and it is on the farms and fields of this zone where desertification must be reversed. Agroforestry combined with soil and water conservation techniques can provide the means of restoring soil productivity, stabilizing erosion, increasing crop yields, decreasing risks to the smallholder through a more diversified production system and of reducing pressure on forest and grazing lands through the production of firewood and fodder from field trees.

6.3 Two agroforestry techniques which appear to have widespread potential for the semi-arid zone in West Africa are Acacia albida intercropping and windbreaks. Windbreaks can begin to increase crop yields within three or four years of their establishment, and may remain effective for perhaps 20 to 40 years. Acacia albida may take about 10 years before they have much effect on crop yields, but they can continue to benefit crop production, conserve the soil, produce fodder for livestock and firewood for cooking during their entire lifespand of 70 to 90 years or more (Kirmse and Norton, 1984).

6.4a A related soil and water conservation technique which has enjoyed great success in Burkina Faso is the use of simple contour ridges to capture rainfall on gently sloping farm fields. The farmers can easily be taught to construct the ridges themselves using a simple hose level, small rocks and dirt. While also controling soil erosion, the technique has become extremely popular with farmers because the increased infiltration of rainwater translates into increased crop yields.

In East and South Africa, the topography is generally much more rugged. Here a variety of erosion control measures combined with linear tree plantings in fields and along trails, roads and steamsides seem to offer the most potential for stabilizing the enviromental degradation.

6.4b To the author's knowledge, there are some combinations of innovative agroforestry and soil conservation techniques that have not yet been tried. What would be the combined effects of Acacia albida intercropping and contour ridging or of windbreaks oriented perpendicular to the prevailing winds and water catchment ridges along the contour? We don't have the answers at this point.

Agroforestry and Declining Crop Yields.

6.5 In all the major agroecological zones, indigenous cropping practices have been developed which permit continual cultivation on a plot of ground. Although many of them involve intercropping, most rely on the addition of animal manure, ashes, kitchen wastes, etc. to maintain productivity. Such sources of soil amendments generally suffice for home gardens or for small fields near the compound, but not for the larger 'bush fields' more remote from the compound where the staple crops of millet, sorghum, maize or root crops are grown. It is on these rainfed upland fields where the difficult problem of declining yields under continuous cropping must result in field abandonment and shifting agriculture.

6.6 Can agroforestry techniques be developed that will permit permanent cropping of cereal crops at relatively high yields in all the major agroecological zones, and achieve this without the use of soil amendments such as animal manure or chemical fertilizer? We have had one significant success towards this goal. Alley cropping has permitted continouous cropping of maize and other crops for six years on IITA's research fields in the humid tropics. As stated earlier, at least this has shown the technical feasibility of the technique, although farmer acceptance and adoption have yet to be shown.

6.7 Alley cropping is more labor intensive than traditional methods and represents a radical change in farming methods. It is difficult to predict how well, and under what conditions,it will be adopted by the farmers. It may be that it will find its greatest acceptance in areas where land scarcity is the most acute, i.e., where shifting agriculture is no longer possible.

6.8 Will alley cropping work in the other agroecological zones? This again requires a good deal of speculation. It certainly could not work in the semi-arid zone without major modifications. With an eight month dry season, the hedge prunings could not yield as much organic matter per year. Furthermore, none of the species used for alley cropping in the humid zone appear suitable for the semi-arid zone, and no likley candidates are apparent. This is especially true for hardy, fast growing nitrogen-fixers.

6.9 The seasonally humid tropics and tropical highlands may be more suitable for alley cropping, but only field trials can tell for sure.

6.10 Whether or not techniques which can permit permanent cropping at high yields can be developed for all zones, all agroforestry techniques which favorably affect soil fertility should allow longer periods of cropping between fallows and shorter fallows. An additional benefit of agroforestry is that all techniques which maintain higher levels of soil organic matter will result in more efficient use of chemical fertilizers. Most tropical soils are characterized by highly oxidized, low activity clays with a small capacity to hold essential plant nutrients in a form useable to the plants. Therefore it is often the amount of soil organic matter which determines the relative ability of tropical soils to retain chemical fertilizers in the soil until crops can make use of them.

Adoption of Agroforestry by Smallholders.

6.11 The rate at which agroforestry techniques may be adopted by smallholders will depend on a number of factors including the following:

-the amount of risk involved

-the type of evidence available to him/her of the advantages of the technique.

-the length of time required before benefits are realized.

-the extent to which the smallholder is dependent on government services or donor projects to implement a proven agroforestry technique.

6.12 The low-resource agriculturalist generally lives such a precarious existence that he can ill afford to make major changes in his farming system if such change entails the risk of crop failure or of indebtedness he is not able to pay back. Most agroforestry techniques are rarely capital intensive compared with other modern practices. If seedlings are provided by a service or a project, the main inputs to the farmer are often his own labor.

6.13 What evidence will lead a smallholder to try out or adopt a new agroforestry technique? The best evidence is to have an example on another farm within a reasonable distance that he or she can visit. All of the villages in the Majjia Valley that do not yet have windbreaks are requesting assistance to establish their own because they have seen the benefits with their own eyes.

6.14 But most farmers in the Sahel have no idea what a windbreak is. Where no local examples of a new technique exist, the extension problem is much more difficult and progress will be slower. This is a good reason for initiating a relatively large number of agroforestry projects well dispersed geographically to start out on a small scale working with the innovators that one finds in any community. These pilot interventions can serve as nuclei on which to build over time.

6.15 The payback period varies considerably for different techniques. Alley cropping may start to improve yields during the first year or two. A live fence, if managed properly, may become effective in one or two years. Windbreaks may begin to produce results in 3 or 4 years. Some fruit trees used for intercropping may begin to bear fruit in 3 years. These time periods shoul be acceptable to many landowners.

6.16a Other techniques may take much longer to get a return on investment. Acacia albida intercropping may yield few benefits for the first 10 years, although the long term benefits may be very substantial. An Acacia albida project may have to be considered a program for the social and environmental well-being of the country with farmers subsidized to plant the tree on their fields.

6.16b Most seedlings for agroforestry plantings are produced in centralized nurseries, usually in cooperation with the national forest service, and distributed out to cooperating villages and farmers at the beginning of the rainy season. In many African countries, the forest service would be incapable of producing and distributing the quantity of seedlings necessary for large scale plantings without donor support. This is because of the cost, logistics and reliable truck transport required for running such programs from central nurseries. Even if farmers become completely sold on an agroforestry technique, this will do little good if they have no source of seedlings of the tree species required.

6.16c The ideal solution would be for the seedlings needed to be produced locally in each village by the villagers and farmers themselves. This would give the farmers the maximum control over the production of the optimum number of the desired tree species, and would greatly reduce the very significant logistical and transportation problems involved with centralized nurseries. A few projects have recently begun to encourage and support the creation of local village, school and private nurseries. The CARE Koro Village Agroforestry Project in Mali and the AID Community Forestry Project in Guinea are two examples.

6.16d Once villagers learn basic nursery techniques, they could supply virtually everything necessary to run a small nursery with the exception of the plastic pots or bags needed for containerized seedlings and, in a few cases, seed when it cannot be collected locally. Plastic bags only cost a few cents each, but are rarely available locally. Ideally, as demand for them increases, merchants would supply them at local markets. In the interim, however, asuuring a supply of plastic bags for local nurseries will be essential to their success.

Agroforestry Research

6.16e IITA pioneered the development of alley cropping and seems to have concentrated its agroforestry research on this technique. ICRISAT in Niger is just now adding an agroforester to their staff. ICRAF's main meddate seems to have been to teach others how to do research on agroforestry; they have only recently begun to conduct their own trials on a significant scale. The author is not familiar with the status of agroforestry research being done by SAFGRAD or ILCA. American universities seem to be involved locally where they are involved in -funded agroforestry development project.

6.16f The main need for alley cropping development at present is to test its farmer acceptance in the humid tropics while continuinuing to refine techniques with station and on-farm trials. Its suitability for highland and seasonally humid conditions also need to be tested.

6.16g Due to the reluctance of development administrators to accept the 1960's research results on the effects of Acacia albida intercropping on crop yields, there seems to be a definite need to confirm these findings. It would seem that ICRISAT or SAFGRAD would be the best suited to conduct this research. The nutrient cyclings capabilities of other agroforestry species used for intercropping and their ability to maintain higher levels of soil organic matter are two other topics that need to be adressed by well qualified and equipped research organizations. Live fencing development, on the other hand, can probably be done best on an operational basis working with individual farmers within the scope of local development projects.

Summary statement

6.17 Although an awareness of the benefits of agroforestry has been growing rapidly in recent years, relatively few development dollars have been dedicated to agroforestry. Still, much has been learned in a few years. One should expect that progress in refining and extending agroforestry techniques would be much faster if greater human and financial resources were invested in this promising technology.

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LOW-RESOURCE AGRICULTURE IN AFRICA

OTA TECHNOLOGY PAPER SERIES
Crop Breeding for Low Resource Agriculture: Overview, Rice, Food Legumes

by

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Crop Breeding for Low Resource Agriculture:
Focus: Africa - Overview, Rice, Food Legumes

Ivan W. Buddenhagen

Overview

1. The development of new varieties of rice and wheat has been the major pump driving the current self sufficiency in food in much of the third world in the last 25 years.. In 1960 no one would have been bold enough to suggest that the burgeoning populations of India, Southeast Asia and Latin America could rely on indigenous food production to avert famine and massive food importations by 1980. But it has happened in spite of the doomsayers and those who protested that the new varieties were instruments of inequity and social and economic imbalance.

2. But the new varieties and the extra millions of tons of production that have already occurred have not just happened because of the new varieties acting alone. If the new varieties had been miraculously adopted on the millions of hectares where they are now grown without any change in other resources--in fertilizer, irrigation, agronomic management, storage, transport, marketing, herbicides, protectants, etc.--exactly where would production levels be today? We cannot know the answer precisely but a good guess is that the world would have produced many millions of tons less of food, but somewhat more than it was producing with the old landrace varieties selected over millennia.

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But there is no reason to believe that the new varieties would have been adopted on millions of hectares without other changes occurring at the same time.

3. Thus, crop breeding is best viewed for the third world as a catalyst of change. If one wishes the existing low resource farmers to remain exactly as they are, one should not invest in crop breeding for them. On the other hand, if one wishes them to be more productive with their existing resources--given only a change in variety--one should expect relatively little increase in productivity, because there will be little adoption and little pressure for adoption (see paragraphs 4 and 16).

4. There are exceptions for some crops in some situations. Each crop and each agroecosystem must be examined carefully to estimate the probable gap in productivity between an old and a new ideal variety, given a change in variety alone. There are general guidelines for making such judgments. They involve: 1) estimates of disease depredations on existing cultivars; 2) estimates of insect depredations on existing cultivars; 3) estimates of soil fertility and its capacity, continuously, to provide higher levels of essential plant nutrients of N, P, K (and of minor elements such as Zn, S, etc.) which are removed by the crop; 4) estimates of negative soil factors such as low or high pH and the negative chemistry concommitant with such soils; 5) estimates of crop/soil/water balance and the degree to which the existing crop exploits seasonal, potentially available water; and, 6) estimates of how well the existing crop supports the temperature regime of the growing season and the changing day length during the season in terms of proper timing of flowering and grain set and filling.

5. If one focuses on a local agroecosystem with all of these estimates one may conclude that a new variety of a local crop may or may not make much difference in productivity. Then one may ask if it is realistic to consider an alternative or new crop. It may be, but one still needs to explore the human possibilities for a new crop in terms of acceptance, adoption, learning, marketing and consumption.

6. For either a new variety or a new crop, breeding and selection research is required. If the focus is on the local agroecosystem in the context of its presence in a certain country which has certain needs and possibilities and on how to benefit it on a continuing sustained basis, one should not ignore a new crop as a substitution for the traditional crops now grown. Often, new crops are either foolishly backed by planners concerned with import substitution and ignorant of ecosystem limitations, or they are ignored completely because of false belief that change in acceptance and adoption is not possible. In Africa, where most staples and many condiment crops are post-1600 introductions, this view is obviously not valid. Cassava, maize, rice, sweet potatoes, potatoes, beans, tomatoes, chillies, etc. are all "new crops".

7. But a major problem remains in judging productivity and its potential change. The elements (actual elements: N, P, K etc.) removed from the local agroecosystem in the crop grain or roots or tubers need to come from somewhere. They need to come year after year, from somewhere. They cannot be created anew nor out of wishful thinking. If existing productivity and element removal is in balance with the capacity of the intact ecosystem to mobilize each year more of each element from decaying rocks and soil particles and biodetritus, then doubling production via a new variety will destabilize the system. Initially it may be

possible, but soon yields will decline to a new balance at the lower level which the ecosystem can generate, of newly available N, P, K, etc.

8. In many of the highly degraded African soils (even in the alluvial deltas), the capacity for continuous element replacement to balance element removal at a high level, is lacking.

9. This emphasizes the original theme: crop breeding should be viewed as a catalyst for change, not as an end in itself by itself. Thus, it is not realistic to view "low resource agriculture" in Africa as potentially much more productive on a sustained basis with varietal or crop changes alone. Some latitude is present on some soils and with some cropping systems but each area needs to be examined on its own conditions, merits and demerits.

10. If one views the low resource farmer as a person operating in a community where inputs from outside his fields either are, or will become, possible, then the potential for new varieties to improve productivity of the low resource farmer goes up to the extent that the additional inputs enable the new variety to outperform the older ones. This can be determined experimentally. But whether the farmer obtains his external inputs locally or more distantly is basically irrelevant to the complications introduced to any analysis since costs, trustworthiness of supply, crop price, transportation, extra labor etc. all have to be factored and these will differ temporally and by location. Moreover, any temporary analysis will not be valid over time if adoption becomes general because regional increases in productivity will depress price. The price depression is especially marked in tropical Africa due to difficulties and cost of transport and to inadequate storage possibilities.

11. This introduction attempts to show that the potential value of crop breeding for the low resource African farmer depends on many things. Some generalities are possible but local analysis is required and many subjective judgments must be made. Probably the most difficult unknown is the haziness in interpretation of the term "low resource agriculturists" in the minds of the writers and readers of this report.

12. In my experience in Africa the low resource farmer wants more resources and wants to make more money. He/she is constrained in these wants by many things, and all stages of change exist, from a primitive, low-productive, balanced state to one of higher productivity, higher risk, higher technology. No report or effort on our part will alter these wants nor the dynamism and destabilizing nature of the modern communication, education and transportation changes occurring in the last few decades in Africa.

13. Agricultural research in Africa should keep up with the dynamic changes it cannot stop and apply itself to figuring out how the changing African farmer can make more money without ruining his/her agroecosystem, and thereby automatically contribute more food to the increasing millions in African cities and towns who cannot grow their own food. The driving force has to be the potential for making more money.

14. The only way to make more money where costs are already low is to increase productivity or produce a more desired product (barring various artificial policy measures to manipulate price). Increasing productivity or producing a more desired product requires: 1) crop breeding (including introduction); or, 2) additional inputs; or 3) changed agronomic practices; or, some combination of the three. History tells us it will be some combination of the three and this will vary with time

and place. The ability to activate change of millions of people involved with low resource agriculture scattered over millions of square miles requires either great force or a very active catalyst. History says there are four great catalysts: 1) fertilizer, 2) machines, 3) "protective" chemicals, and 4) new varieties and crops. The past primitive agriculture of the now agriculturally advanced nations was transformed by the first three catalysts before crop breeding became very important (although new crops were also involved)(Loomis, 1984). In third world countries, food crop agriculture remained largely unchanged until the catalyst of crop breeding was pushed vigorously, beginning about 1950. This push was combined with a very logical and essential push on fertilizer, and for rice, also on "protective" chemicals.

15. Should or could tropical Africa follow a different course? I think, basically not. The catalyst of most potential for Africa is new varieties (and a few "new" crops) combined with some fertilizer. These will generate income and interest which will be applied to labor-saving and ecosystem conserving implements, machines and chemicals. There will be a concern to "protect" higher yields and here is where wise crop-breeding will need to be applied from the beginning to minimize future pesticide usage (Buddenhagen, 1983a-e).

16. For crop breeding or crop introduction to be of sufficient value so that new varieties will be adopted readily without any other inputs or changes in a peasant agricultural situation in Africa, certain very specific factors must exist. Usually they do not exist anymore, hence the low adoption now where no inputs are possible. One or more of the following key factors must exist:

a) The existing landrace varieties or clones encompass a small genetic base and their adaptation to the local environment is considerably less than is represented by the species as a whole.

b) The existing landrace varieties or clones are overly susceptible to a disease or insect pest for which resistance can be developed.

c) The indigenous crop is not as productive or environmentally tolerant or its final product is not of as good quality as a potential substitute crop domesticated elsewhere.

d) Existing varieties do not contain any hybrid vigor and hybrid vigor is potentially developable.

e) A completely new crop has adaptation and adoption potential to fill an environmental and product niche now empty or insufficiently filled.

f) For legumes only, the inability to nodulate (and thus produce their own required nitrogen) with indigenous soil-borne nodulating bacteria (Rhizobia).

17. Examples exist in Africa for each of these situations. For a) cassava and maize, with limited original introduction from the American centers of origin; For b) cassava, maize, and rice, all susceptible to different indigenous African viruses and to other pathogens and pests; For c) cassava has substituted for indigenous yams, peanuts for indigenous bambarra groundnuts, maize for sorghum, beans for cowpeas, Asian rice for African rice, etc. Potentially, high lysine maize can provide an improved dietary product; For d) hybrid maize yields better than mixed varietal maize, even without inputs, and under stress (IITA 1985a). For e) historically in Africa: cocoa, rubber, pineapple, bananas, cassava, maize, tea, etc. More recently, soybeans.

Potentally, lima beans. For f) Soybeans introduced from USA failed to nodulate and fix nitrogen with indigenous African soil Rhizobia. It has been possible to rectify this deficiency through breeding (IITA 1985b).

Rice and Food Legume Breeding

18. Food legumes in the African tropics include cowpeas, common beans, lima beans, soybeans, peanuts, bambarra groundnuts, pigeon peas, chickpeas and a few other minor legumes. Rice consists of Asian rice (*Oryza sativa*) and, of much less importance and potential, African rice (*O. glaberrima*). But rice breeding must emphasize an ecosystem focus, in which different rices are needed for different rice ecologies: upland, irrigated, hydromorphic, swamp, mangrove, deep water, etc. (Buddenhagen 1978).

19. All the crops (except pigeon peas) are inbreeding species, which means that every plant will breed true (identical descendants) and thus the farmer grows a single type, or a mixture of single types (a landrace), saving his own seed which will reproduce the same types year after year. (There may be some low level of natural outcrossing and recombination of characters over time). It is only through mutation and recombination of characters through outcrossing that a population may be "improved" for local adaptation to environmental stresses, and for productivity. Plant breeding for these crops attempts to do just that--to recombine characters from several parents by crossing, and then select the better progeny for about 5 generations as the genes are reassembled, before a "fixed" breeding line is obtained. During these segregating generations the breeding team needs to apply pathogen or pest or other stress pressure so as to be able to retain only the

"resistant" progeny, which also must have desirable agronomic and product characteristics.

20. Thus, breeding is a long-term and a continuing endeavor. Progress made must be retained as further progress is sought. New problems are revealed by the development of new varieties which had unforeseen weaknesses or whose presence generates new levels of disease or pest damage from heretofor minor pests and pathogens (Buddenhagen, 1983b,d,e).

21. To date, in Africa, crop breeding has inherently meant replacing old landrace mixtures with a pure line variety. This has been criticized on the basis that the "buffering" effect of the mixture in relation to diseases, pests and environmental stresses is thereby lost and the new variety will be more "vulnerable" to new epidemics or to environmental stresses.

22. Although this may be true to some extent, there are no hard data to prove the point. Moreover, with the right kind of breeding, providing durable resistance to disease and pests and higher levels of stress resistance (Buddenhagen, 1977, 1983a-e; Buddenhagen and dePonti, 1984), the new pure line variety should suffer less depredations from these factors. Moreover, the pure line could stabilize the evolution of new races of pathogens which would otherwise be more variable on a landrace. Contrarily, if a mixture of varieties really is superior long-term, a breeding team could resynthesize a mixture of superior pure lines to make a bred "landrace" superior to the old landrace.

23. The benefits of rice and legume breeding in Africa are potentially high if breeding is utilized as a catalyst to bring about agricultural change. For this, the activity should be organized within a "crop improvement team" and contain professionals in different scientific

disciplines. The group can study the farm situation in the area selected as the target area for a new variety and thus form realistic and sharp objectives. The team will need to contain extension personnel or be linked directly with them. The overall activity can greatly strengthen technical organizations since it involves different researchers in useful problem solving and agriculture-enhancing focused objectives. The same might be said for the institutions involved but there is a problem in "who should do it." In general, in Africa, the centralization of problem solving agricultural research at Universities wherein teaching, experiment station research and cooperative extension work together, does not exist. Crop breeding is left to federal departments of agriculture or less commonly to a few federally organized crop institutes. The advantage is that the concept of team organization is thereby possible. The disadvantage is that the in-depth research and long-term commitment possible at an agricultural university may be lacking. The separation of research and extension activities in organizational structure also slows accomplishment in relation to crop breeding.

24. The potential payoff in crop breeding in social and economic terms is very great. If the rice or food legume crop now yields 600 kg/ha and a new variety will yield 800 kg/ha with essentially the same management, then there is a 33% gain in productivity. But the farmer's profitability (given the same price for product) may be doubled, tripled or go up even 10 times. It depends where the break-even point was before. Thus, the buying power of the farmer can be greatly enhanced, enabling the cycle of purchasing inputs to enhance yields further or to lower drudgery. In many countries, local entrepreneurs may be

stimulated to develop these inputs, whether they be small machines or fertilizer mines or factories. In the case of rice, the potential of increased profitability will stimulate increased development and use of wetlands--the major under-utilized agricultural resource in tropical Africa (Juo and Lowe, 1986).

Status of Rice and Food Legume Breeding in Sub-Saharan Africa.

25. Rice: Each rice ecosystem (Buddenhagen, 1978) requires individual analysis and space does not permit that here. The bottom line is that improved varieties exist for each of the climatic subregions in Africa for irrigated systems and they can be 1) improved further for local African stresses; and 2) adopted on a wider scale; and 3) utilized to promote rice paddy development on a much broader scale. The current upland rice (which is predominant in West Africa) cannot be helped much by breeding, and further investment here is unnecessary and counterproductive to stabilizing agricultural productivity. The specific breeding objectives requiring further input are: resistance to bacterial leaf blight, blast, African rice viruses, plant and leaf hoppers, *Diopsis* and other borers, panicle diseases, iron toxicity; and adaptation to direct seeding in paddies.

26. Varietal improvement needs to be more than matched by development of the enormous wetland potential for rice (and other crops) to stabilize African agricultural potential (Andriesse, 1986 and see map). Thus, rice breeding should be viewed, not in terms of adoption of new improved varieties but in terms of potential stimulus for expansion of irrigated rice paddy development (Buddenhagen, 1986a). Any investment in rice breeding needs to be linked directly with investment in wetland development. Thus, traditional development assistance in one or the

other alone is deficient in realizing payoff. Opportunities should be obvious here, in restructuring investment, AID projects, and support to international crop centers.

27. National programs of rice breeding which can be considered as fairly good exist in only a few countries of Africa. Accomplishments of the West African Rice Development Association (WARDA) in rice research have been minimal (also in rice development). Their efforts recently to back individual country research efforts for specific ecosystems of regional scope are basically sound but the politics of the system overwhelms the science and an honest efficient approach to regional needs. (As an example, the push to continue at Bouake, Ivory Coast a major research effort on upland rice is not a cost effective investment in terms of regional needs for rice opportunities.)

28. The International Institute of Tropical Agriculture (IITA, the one IARC for crops and farming systems located in Africa) had a good but small and underfunded rice improvement program which accurately determined priorities and opportunities (Buddenhagen and Persley, 1978) but which was unable to follow-through for long in action. The interinstitutional rivalry for control of rice improvement in Africa among WARDA, IITA and distant IRRI (the International Rice Research Institute) in the Philippines has been a major impediment to progress and efficient use of financial resources. The preponderant position of IRRI in distant Philippines, with its great success in Asia and its "world mandate" for rice research has greatly limited the potential of IITA's rice research and development program for Africa. Moreover, IRRI's continued interest to dominate rice research in Africa with an Asian bias and a distant center of control is, in my view,

counterproductive to African needs and opportunities. A major rethinking and solution of "who can best do what", and of the investment in the concept of "world mandates" in the CGIAR system should be sought immediately, if the real needs of tropical Africa are to be addressed honestly by US AID and by other donors. [This key fundamental problem goes beyond rice and involves especially also, the future of maize and cassava in Africa.]

29. Because the wetland areas of Africa cut across the African climate regions, major opportunities for rice exist in 4 of the regions designated in the OTA climatic sub-regions of Africa. These are: 1) Arid and semi-arid tropics (ASA); 2) Subhumid tropical uplands (HST); Humid equatorial lowlands (HEL); and 4) Madagascar (IIS).

30. In general, there has been essentially no input from US universities into African rice needs and opportunities.

31. Food legume breeding in Africa includes major efforts by IITA on cowpeas and soybeans, a recent moderate effort by CIAT on common beans in East Africa and a moderate recent effort by ICRISAT on peanuts in East Africa. Earlier limited efforts occurred in colonial times on beans in East Africa and limited work has continued on a national basis in a few East and Southern African countries subsequently. Efforts of the French organizations in their ex-colonies has stimulated some work, but mostly on soybeans. Efforts of IITA on soybeans and cowpeas has stimulated considerable involvement of national programs but usually this is in testing new materials rather than developing home-grown breeding programs. A similar pattern has been established recently by CIAT in East Africa for common beans.

32. For food legumes, the major emphasis in Africa has been and should continue to be the stabilization of production through increased disease and pest resistance, development of short-cycle varieties, and improved nitrogen-fixing ability. Major advances in yield potential per se should not be expected. The other real opportunity is the expansion of new crops in specific areas. Specifically 1) soybeans for home use and local edible oil country needs; 2) lima beans for the lowland tropics where other legumes are not adapted (areas classed as Hcl (Humid coastal lowlands), and HEL). Also in the subhumid tropical uplands (HST). Today lima beans are a completely neglected crop and opportunity; 3) pigeon peas in the ASA areas; and, 4) chickpeas in the highlands (TH, STH) and in Madagascar.

33. The stimulus for these activities at the National level appears to be lacking, except for soybeans, wherein some local governments see real opportunities for cutting edible-oil imports. This is a laudable endeavor but it should be linked with development of local food uses at the village level.

34. Most "national" programs conducting food legume improvement are stimulated by the international institute efforts and linked to these and thereby to foreign assistance. So far these are mostly for research on soybeans, common beans and cowpeas. The major opportunities for soybeans are in the HST, HEL zones and in Madagascar. For cowpeas, in ASA and HST zones. For common beans in TH and STH zones and in Madagascar. Lima beans have potential in HST and HEL and in Madagascar. Pigeon peas in ASA and HST.

35. It is unrealistic to attempt to provide figures now on adoption of new varieties in Africa. Firstly, the figures won't be accurate; secondly they won't show the real effect of introduction/development/breeding efforts which are to change levels of total production, as well as to add new crops--not just to replace old varieties with new ones. Thirdly, how much new varieties should be adopted and are not is dependent on the extent to which the shift would be beneficial locally. That will vary from place to place and requires information not now existing. Fourthly, new adoption is underway and constantly changing--it depends not only on infrastructive and outside push but on the quality of any new varieties developed--and these are constantly changing.

36. The idea that new varieties are not scale neutral is an old one not supported by recent research. Perspective may be provided by realizing that production (farming) activities for a base level of yield are the same, regardless of variety. New varieties, if properly bred, will be just as good or slightly better with the basal level of farming, than the old varieties (where this is not the case it was poor breeding). With increased levels of care or inputs the new varieties will outdistance the old ones. The extent to which the extra care or extra inputs are available to the farmer or are provided by him/her will vary with his/her aptitude, ambition, finances and credit, and risk predilection. Clever farmers will forge ahead of dull ones. Moreover, even without extra inputs, who will get the new seed? At first, the clever ones, those accessible by communication and transport, those who are opportunistic, those with "connections." To this extent, no attempt at change is neutral. But the growing of the new varieties is scale

neutral. This is especially so for the food legumes where added nitrogen is not needed for their potential to be realized.

37. In general, there has been little input from US universities into food legume improvement in Africa. The exceptions relate to the bean/-cowpea CRSP program with a limited connection on cowpeas in Senegal, Cameroun, and Nigeria and with common beans in Malawi and Tanzania. These programs have not been well linked with the IARC's efforts in the same countries, but their efforts have been useful especially in education of Africans.

38. A list of 8 principles for "managing ... resources for low-resource agriculture" has been provided by OTA as a guide to preparing a table wherein the general principles are addressed in terms of what needs to be done, how to do it, who should do it, what limits it. These principles have been addressed in terms of the specific topic of crop breeding, placed in a holistic view of research and development in Africa (Table 1).

TABLE 1

Principle A: Low resource agriculture includes ecological, social, economic and institutional components. Systems analysis approach.

What needs to be done	How to do it	Who should do it	What limits it
-analyze within country ecosystems for optimum crop use	-utilize exisiting data gatherable from various sources and gather new data	-National & state programs, linked with IARC's, especially with IITA, and with overseas university expertise.	-lack of ecosystem analysis education
-apply analysis to land value and capability	-focus on a major crop for each subdivided area and examine its needs and opportunities	-State or national programs, and local universities if they are so structured, linked with IITA and overseas university expertise	-lack of vertical integration in research and development
-apply analysis to crops, as part of a cropping system	-fit in subsidiary crops (and animals) as they will honestly fit, in a systems approach	-local projects of US/AID, World Bank, FAO, GTZ, etc., linked with appropriate state, national, and international bodies	-perceived lack of payoff in that positive changes require extension efforts now inadequate and they require much push with money
-apply analysis to social, economic, and institutional considerations	-involve social scientists while setting breeding targets	-breeding team needs to provide leadership for this	-lack of focus on one or a few actual objectives that are realizable
-improve linkages between African agricultural Universities and Departments of agriculture and extension.	-hold subject focused workshops across organizations	-African leaders of these organizations -any aid agencies supporting their activities	-protectionism, funds, lack of perception of need

Principle B: External linkages: resources, institutions, individuals.

What needs to be done	How to do it	Who should do it	What limits it
-support US University involvement, where expertise exists, in one-to-one linkage with African scientists in collaborative research projects	-develop collaborative research projectsfor specific targets	-USAID funding -Non-USAID leadership and execution. Model research support after the system used by the Australian Center for International Research (ACIAR)	-lack of money and leadership -Bureaucracy and low level of present funding
-analyze or make available to research planners and policy makers and scientists in Africa, including the IARC's, country by county fertilizer production potential and projected use curves for different levels of production, based on sound economic considerations	-gather, publish and promote data and analysis	-International Fertilizer Institute, Mussol Shoals in collaboration with industry and African country experts	-lack of focus and perceived need for this objective by IARC and National Scientists and Ag. research planners and leaders
-remove conflicting IARC turf fights over who is to do what in Africa	-remove the "world mandate" concept from IARC planning and operations. -Where present crop assignments conflict, assign IARC responsibility in Africa to a center or centers located in Af with top management residing in Africa	-IARC donors, especially USAID, the major donor and the World Bank	-vested interests, past history and indadequate knowledge on part of donors of the nonscientific and destructive nature of the "world mandate" (i.e. central domination from afar) concept
-for rice paddy development, increase US and Dutch participation to include also the private sector	-plan this objective with national African policy makers for agriculture World Bank, etc.	-USAID, World Bank, ADB, FAO	-focus, leadership and funds

Principle B: External linkages (continued)

What needs to be done	How to do it	Who should do it	What limits it
-link existing development projects more closely with knowledge and present activities and future plans of work of IITA and other IARC activities in Africa	-require this objective of leaders of existing development projects and educate both them and the organizers of development projects of this opportunity -fund a research component in each development project and assign IARC ro liaison responsibility to this component	-agencies in charge of development projects such as US/AID, FAO, IFAD, World Bank, etc.	-lack of realization that the knowledge base for project objectives is inadequate and that help is available -vested interests in project control -paucity of IARC interest and concern for development (as opposed to research)

Principle C: African farmer response to risk:

-Breeding teams need to talk to farmers to fully appreciate their risk and profit concerns	-do it	-the breeding team and extension agents	-not perceived as important by scientists because of lack of training. Also, travel funds
-Breeding teams need to talk to farmers and consumers on breeding objectives early in program	-deal with village heads and individuals -hold workshop with farmers	-the breeding team and extension agents	-not perceived as important. Also travel funds
-Breeding teams need to talk to traders (buyers, wholesalers) to learn their opinion on product needs and quality and on price	-hold one-to-one discussions	-breeding team leader	-not perceived as important. Also, travel funds.

Principle D: Local resources: knowledge, practices, institutions, germplasm

What needs to be done	How to do it	Who should do it	What limits it
-stimulate national breeding teams to creative research and ecosystem analysis	-improve quality of those sponsored for Ph.D. studies -be more selective of where Ph.D. training is carried out	-the IARC concerned with the crop for Africa. Also FAO, funding agencies and selected universities training Africans	-inadequate focus and knowledge and concern for these areas in the IARC's. Also at Universities where training is conducted -centralization of research at IARC's with insufficient effort to cultivate research creativity by nationals for local needs -utilization by the IARC's of national scientists as technicians rather than on a one-to-one basis as collaborating scientists
-stimulate such teams to analyze local genetic material, its deficiencies and to analyze local buyers and consumers desires	-as above	-ditto	
-stimulate analysis of events and losses from harvest to consumption	-back more work on postharvest processes and losses -involve more women who actually cook the product -back more work on product utilization	-ditto	

Principle E: Heterogeneity of low resource agriculturists

- not very applicable as a problem in crop breeding and new varietal use

Principle F: Gender effects

-assure that local women's opinions are known in setting breeding priorities, especially on product quality.	-talk with them -hold workshops	-breeding team	-no women in breeding program -not perceived as important
-train more women in plant breeding and related disciplines	-provide fellowships for this objective	-US Aid, other funding agencies	-funds, absence of this as an objective

Principle G: Management for sustainability

What needs to be done	How to do it	Who should do it	What limits it
-link crop breeding with farming systems knowledge and analysis	-link with practical economists and soil scientists	-stimulus from IARC's and AID agencies for discipline linkage	-rigid discipline education
-avoid creating mini national IARC's in Africa -avoid creating separate crop institutes such as a rice research institute	-develop research with more local backing, as it can be sustained financially	-put a brake on grandoise plans by AID agencies and others to expand research beyond local ficial needs and sustainability. Initiative needed from aid agencies and IARC's and local planners	-grandoise empire building urges and stimulus for copying IARC's
-educate Africans on how agricultural research is financed and managed in developed countries	-insist on such training as part of University experience	-Fellowship funders	-non-identification of need
-work toward increased productivity commodity tax for research support	-develop local growers cooperatives and include this as an objective	-local agricultural groups	-no such heritage or education

Principle H: Local participation

- Local participation in creative research and planning and execution of research in crop breeding is needed and should be encouraged by collaborative project interaction with IARC and overseas university scientists.

39. Regarding the table, most points are self explanatory but I should emphasize the need for both regional and focused local agroecosystem analysis (see Principles A&D) and the need for conducting baseline studies on present crop production levels and constraints. While breeders are busy attempting to make better varieties, there are almost no hard data that indicate the level of disease and insect depredations on existing landraces in farmers fields, or on existing yield levels and stresses under actual farm conditions. Research needs to be backed financially for such studies (see para. 4, 16) for each target crop and ecosystem. The best example I know of a regional ecosystem analysis with a crop focus is that of Carter (1986) entitled "Climatic and edaphic classification on a continental scale for cassava in South America." It is this type of baseline study that is needed in Africa, to provide a framework for local ecosystem analysis, which can then result in project development and in focusing research objectives for a practical payoff.

40. Under principle D, one could emphasize that there has been almost no effort to grow diverse genetic material in farmers fields or in simulated farmers fields and under farmers conditions. This would be useful for food legumes so that types superior for the low resource farmer could be identified and used in breeding. This needs to be combined with growing under more controlled conditions where pest pressures can be applied artificially.

41. Under principle C (Risk) and G (Sustainability) there is a key technical component not mentioned in the table but elaborated here. The most important aspect of developing new varieties is whether or not their perceived improved performance will be stable in yield throughout

the area where they are to be grown and whether or not the resistances to the pests and pathogens which they carry will be durable (last for a long time). It is of critical importance in not increasing risk and in maintaining sustainability for the low resource farmer that new varieties are stable and their resistances are durable (Buddenhagen 1983a-e; Buddenhagen and dePonti 1984; Johnson 1984). The record of new varieties for the third world in recent years has not been very good. Thus, major efforts should be made in plant breeding research to figure out how to breed for increased stability and durability. Today this is not being done and there is no support for basic research in this most critical area. In addition to the routine breeding at the IARC's, which is copied by National programs, research should be backed to lead to solutions of instability and collapse of resistance of new varieties by influencing varietal development strategies and methods. This will require the financial backing of research at a few US universities where scientists are interested in this subject and also concerned with international agriculture. Innovative new research is needed and it ideally can be carried out by Ph.D. students who themselves wish international careers. Focused financial support in this area is needed and its absence is the main limitation to conducting the research which could result in great risk reduction in low resource farming in Africa.

42. Policy issues: US exports: It is unrealistic to expect that black African countries should be importers of US rice or food legumes, or that they really are or will be in a position to pay in hard currency for such products. The only possible exception is countries producing much oil, especially Nigeria. But such countries will attempt to spend some of their oil money on their agricultural sector, so they will block

imports anyway, or tax them at a high level, to make their local production competitive. American oil companies are and will be pressured to assist in local agricultural development -- potentially creating an opportunity for American agribusiness and University expertise in research and development. Thus, US policy should not be dictated by the farm block with false expectations of export to poor countries. This also includes soybeans, whose production should be stimulated locally in black Africa, both for village use in nutrition (especially babies), but also for in-country edible oil needs where appropriate.

43. Policy issues: self-sufficiency: Although it is a desire of African leaders to be self-sufficient in food, this is an unrealistic and counterproductive target. Each agro-ecosystem should be encouraged to produce the product(s) it is most suited for in terms of sustainability and profitability. Tropical forest areas should not be expected to produce cowpeas, beans, maize, sorghum, etc. They could produce rice and soybeans. But tree crops would be best: oil palm, cacao, rubber, etc. Excess products from one zone can be traded for excess products of another. Thus, with the objective of use of the agro-ecosystem for production of crops most adapted, transport and trade both within countries and among neighboring countries is needed and should be fostered. Plant breeding should not be pushed into having unrealistic targets where crop adaptation is just not on. Substitute crops more adapted can be sought, but within limits.

44. Policy issues: cash crops: Much has been written about cash crops (they are generally regarded as bad) but what is seldom realized is that all crops are cash crops beyond home use needs, and most farming, even of the low resource farmer in Africa, is done for one reason only -- to

make money (Buddenhagen, 1986b). A crop reaches the economist's concept of a cash crop when there is much surplus that is transported, traded, and sold in large quantities. Where this occurs it is because the crop is being grown in a location where it is well adapted and it is sufficiently productive to be profitable. Much of plant breeding and agronomy research is targeted to determine just that -- a best match between a crop species potential and an environment. The result is profitable productivity, and a cash crop.

45. *Policy issues*: *opportunities*: Wetlands as a prime opportunity for long-term productive sustainable agriculture in Africa has been emphasized (para. 24, 26). It should be realized that the civilizations and large populations of tropical Asia were made possible by wetland development thousands of years ago. It should be realized that in the lowland humid tropics the choice is either (or both) tree crops, and wetland development for food crops, with rice as the primary crop. Secondary food crops are then possible. Sustainability of agriculture in vast areas of Africa is possible only by these two routes. To shy away from this wetland development because of the capital requirements and to expect instead short-term fixes to the basic agricultural intractability of upland agriculture in the tropics is, in my view, bound to fail. Especially in Africa with its current and projected imbalance of birth/death rates. What is needed is to link crop research and land development together as an investment opportunity for the long-range benefit of Africa, and thus mankind. This will take a lot of creative financing, creative small-scale projects, and a lot of education. It is a Herculean but worthwhile task.

46. Policy issues: Fertilizer: Increased productivity will require increased fertilizer use, whether or not plant breeding is carried out (para. 4, 7 and Principle B in Table 1). Every effort to combine both with local production of fertilizers should be encouraged and stimulated. To think in utopian terms, with the burgeoning human populations in Africa, that the wild or pristine ecosystem, untouched by modern science and agronomic principles, can feed the African population, or can produce food at a price millions of Africans can afford is to think unrealistically. This is not what will happen.

47. Policy issues: Population growth rates and city/village changes: Population growth rates cannot be separated from food growth rate needs. This sensitive issue needs to be addressed in Africa. Population growth rates are too high and much funding and effort should be made in education to enable women to have no more children than they want. Much propaganda and evasive rhetoric obscures the point that millions of African women are unable to limit their family size as they (and their men) would like because of ignorance and lack of means. In my view, much could and should be done and it is important that crop scientists not assume all the burden (nor propose crop breeding solutions) for feeding an unchecked population that is already out of balance with agro-ecosystem sustainable productivity. Here is where much support to women's education, and involvement of African women in policy and teaching, is most sorely needed. The other aspect of production/consumption is the rapid and continuing population shift from countryside to cities in the tropics generally. Complex forces stimulate this but the net result is to require better transport and storage and processing of food

on a large scale. Policy and funds should be directed toward these three objectives, also.

48. Policy issues: Product substitution: Starch, man's major staple, can be produced by many plants. Protein likewise. Similar products can be made from basic foodstocks of many different crops. Too little effort has been given in the tropics to research and development of desired food products based on well adapted tropical crops. The traditions of the "developed" world of non-tropical people in non-tropical ecosystems, combined with the education of Africans in such non-tropical locations, has tended to slow the development of innovative work on adapted tropical crops for processing them into desired products. Look at the rising wheat-bread consumption rates in Africa as an example of the trend. Policy, education and funds should be directed at research and development of good food products locally and their commercialization, from adapted tropical food crops.

49. Policy issues: Support to IARC's and US Universities: The IARC's have been and should continue to be major catalysts in bringing about agricultural change in Africa. Support to them should continue but reform is needed in three basic ways: 1) The Center located in Africa, where it has a mandated crop also handled by a Center outside Africa, should direct the IARC research for that crop in Africa and request help where needed -- from the other IARC's, from Universities, from wherever. This has been discussed in para. 28 and in the Table under Principle B, in which the key needed change is to remove the "world mandate" concept from the IARC system. In my view, only by concentrating leadership and funding with the IARC located in Africa will African needs really be served well and efficiently for the particular crop. Where there is no

inter-IARC competition for funds for a geographic and clientele target for a crop, there is still a problem in leadership and efficient use of funds for African needs (such as for peanuts, beans, sorghum). Probably the best solution is to develop a crop center in a zone that can handle the majority of such crops and delegate more autonomy to it (and more funds) to work on African needs but still with close linkage to the parental institutes. By providing more research autonomy, the Center will be more free to be flexible in approaching the African scene and to use more sources outside the parent institute (such as US universities) for back-up and collaboration. The second basic reform is to support more long-term knowledge-building research at the IARC's and to reduce the concept of measuring success by the number of varietal trials dispatched. This present bias has grown out of the original breeding approach which led to the institutes' success and to the reward system so generated (financial support and accolades) for flash-in-the- pan "discoveries"). It is time to move beyond that stage and establish a more solid research base and a more equal approach in dealing collaboratively with scientists in national programs and local universities. It is indeed striking to see how little the IARC's deal with national universities or their scientists in their activities, even though they have been educated largely in US universities where the land grant university system is the fundament of long-term progress in agricultural research and development. The third basic reform is develop more collaborative projects with US based scientists (with the IARC's). At present, IARC research is largely autonomous and beyond review by scientific peers and thus it can become both narrow and hierarchical. More funds going to the IARC's should be earmarked for the development of collaborative projects with US based scientists and for Ph.D. fellowships for Americans to do research connected with IARC interests, but based at a US university. Only in this way will the narrowness of IARC research be broadened and the great opportunities for useful scientific research in the tropics which are now being ignored, be addressed. At present, considerable connection in this way exists with European and Japanese donor funds to IARC's, tying their universities (and their future scientist expertise) with the tropics. The US should follow this example. (This American hands-off attitude extends to our contribution to FAO. The major plant breeding innovation useful for third world farmers -- a focus on stable and durable resistance -- was developed by FAO and staffed only by young men from the Netherlands under the FAO "Associate Expert" program. The US does not earmark any FAO funds for the "Associate Expert" program, so young Americans do not have this opportunity for training and research overseas -- and thus for future contribution and influence to third world agriculture from this FAO springboard.) Additionally to earmarking IARC funds for US university collaborative projects, funds should go directly to carefully selected US universities for a long-term commitment to African needs and principal investigators should develop linkage as they see fit, and are able to do so, with both African university or national program scientists and with IARC scientists in a 3-way arrangement, but with leadership from here. This will broaden the addressing of basic research needs which are now largely neglected by the "short-term result" and "instant solution" bias used in deciding IARC funding and priorities.

50. Policy issues: Training of scientists for Africa: US/AID, IARC and other agencies support graduate training of Africans, but usually not for non-Africans who would wish careers in Africa. Two points are important: 1) Selection of the African student, the university for study, and the major professor should be more stringent. One of the criteria in student selection should be to find smart students who wish to do tough but creative field work rather than to isolate themselves in esoteric laboratory research to obtain foreign journal accolades. University selection should be where there is commitment to Africa and to thesis work overseas and where professors with these interests and experience exist. It is important to build on long-term university and professor commitment. Additionally, some concern should be given to selection of universities where African crops can be grown and where a subject area of need (such as resistance breeding) is handled in depth. It should be recognized that where fellowships are not provided by an agency interested in Africa, a professor will support an African student on his "basic research grant." Thus, the student will do research on a basic research cutting-edge area for publication in a prestigious journal. Usually this research will have no relevance to African needs, and thus the student training and orientation will be irrelevant. When the student returns, he/she will wish to continue in the same research path and create a mini copy of the esoteric research learned abroad. The solution is to fund fellowships for students for Africa and to be selective as indicated above.

- The second point of importance is that too few non-Africans are being supported for graduate study on African problems, i.e., too few Americans. Training Africans and Americans side by side to address

African problems has many advantages, not least of which is to broaden the African students' experience and research thinking. Americans have something special to offer in their practicability and faith that they can bring about useful changes and discover new and useful things. Africans need this exposure. At present, the IARC's in Africa support fellowships only for Africans. At the same time, they are staffed mostly by non-Americans and non-Africans. The future involvement of the US in, and its potential contribution to, African agricultural science is being short-changed by this basic policy. The solution is to earmark funds for American graduate students (not ignoring American minorities) who wish an international career to do Ph.D. studies relevant to African problems.

51. Policy issues: National/Regional relationships: There has been, and continues to be, interest in creating African-run organizations in a specific country which would have regional scope and authority. WARDA is an example. These organizations are, and would have to continue to be, largely funded with external (i.e., US and European) funds. There are several basic reasons why this approach to African research and development is counterproductive. First, a stage is set for a potential political conflict in relation to control: African/non-African. Cutting back, reforming or eliminating the organization becomes so politically sensitive that no one has the guts to do it, to state the facts bluntly. Second, national responsibility and national organizations are inhibited (i.e., "Someone else will do the job and we don't need to invest in our own problems"). Third, the organizations emulate the IARC's or FAO, compete with them, and set staff rewards at that international (and artificial) standard. This further undercuts

national program development and staff morale and pits everyone against everyone else in a struggle to get the high-salaried international post. Fourth, inter-African country rivalries and past and future problems inhibit a magnanimous approach to solving regional problems through regional African organizations. There are better ways to accomplish the necessary agricultural research and development needs. First, a non-African-run international center (i.e., IITA) can be somewhat insulated from inter-country squabbles and rivalries and it can catalyze positive interaction among African scientists on a neutral ground, cutting across language and East-West-South differences. So that type of international organization should be backed to the hilt. Second, where the national will and expertise can build home-grown and home-funded good research, that is what should be fostered, for it is that research which will become nationally useful and thereby stimulate pride and long-term national commitment. Third, national accomplishment in agricultural science will spread naturally through normal professional society interaction, through publications and through scientist-to-scientist exchange of letters, ideas, seeds. This whole area needs fostering and funding. Funds should be earmarked for workshops, attending regional and international scientific meetings and for the nurturing of professional societies.

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A LIST OF ACRONYMS/GLOSSARY

Page	Acronym/Term	Full Name/Common Name
2	N	Nitrogen
	P	Phosphorus
	K	Potassium
	Zn	Zinc
	S	Sulfur
11	*Diopsis*	Stalk-eyed fly
12	WARDA	West African Rice Development Assoc.
12	IITA	International Institute of Tropical Agriculture
12	IARC	International Agricultural Research Center
12	IRRI	International Rice Research Inst.
13	CGIAR	Consultative Group on International Agricultural Research
13	US AID	United States Agency for International Development
13	OTA	Office of Technology Assessment
13	ASA	Arid and Semi-arid Tropics
13	HST	Sub-humid Tropical Uplands
13	HEL	Humid Equatorial lowlands
13	IIS	Madagascar and Indian Ocean Islands
13	CIAT	Centro Internacional de Agricultura Tropical
13	ICRISAT	International Center for Research in Semi-arid Tropics
14	TH	Tropical highlands
14	STH	Subtropical Highlands
16	CRSP	Cooperative Research Service projects
17	FAO	Food and Agricultural organization
17	GTZ	German Technical (Aid)
18	ADB	African Development Bank
19	IFAD	International Fund for Agricultural Development
20	Ph.D.	Doctor of Philosophy

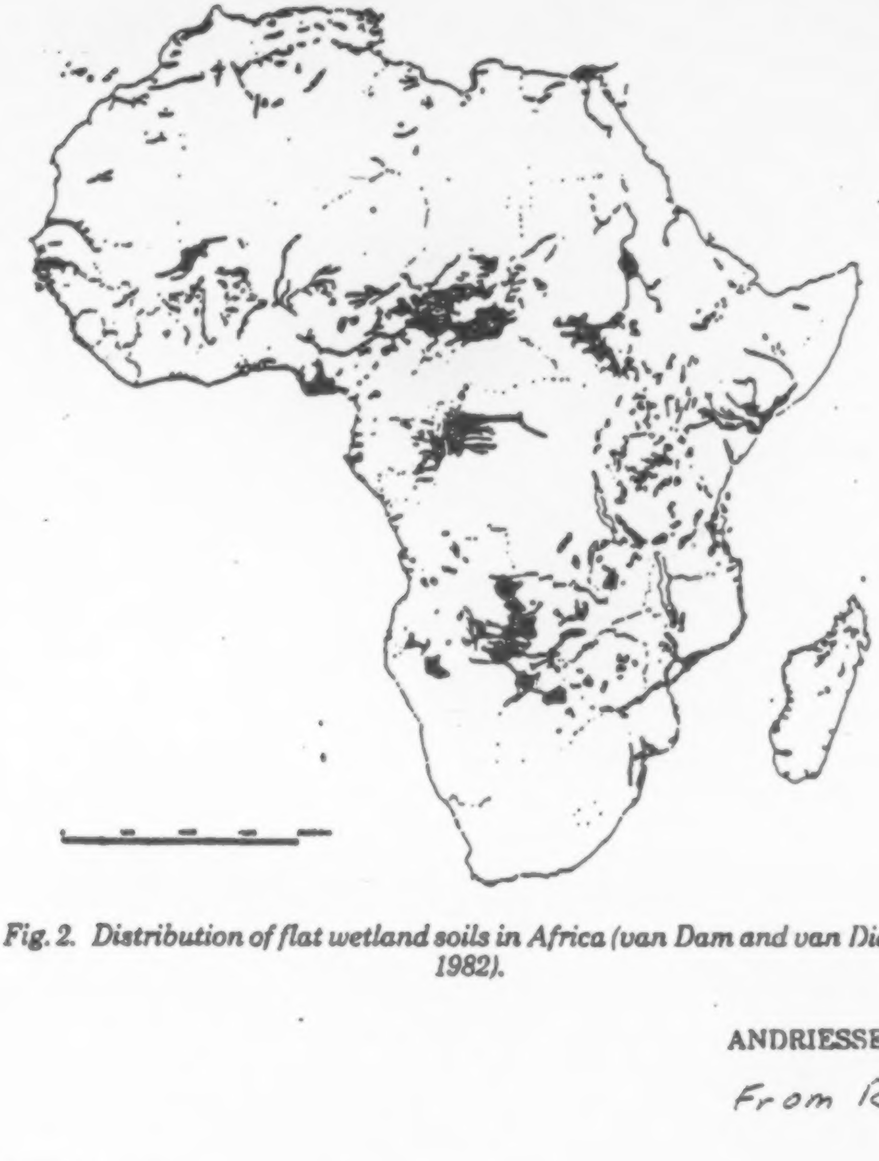

Fig. 2. Distribution of flat wetland soils in Africa (van Dam and van Diepen 1982).

ANDRIESSE 19

From Ref. 1

FINAL DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

MILLET BREEDING FOR LOW-RESOURCE AGRICULTURE IN AFRICA

by

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FINAL DRAFT

Revised 1/[illegible]

OTA Technology Paper Series:
Millet Breeding for Low-Resource Agriculture in Africa

David J. Andrews[1]

ABSTRACT

1. Summary. The breeding of new millet varieties will be essential for increasing food production in the existing regions of Africa where they are important cereals but must be accompanied by complementary agronomic and crop protection research. A major constraint to increased millet grain production by small holder farmers is the lack of firm food grain markets.

There are many technical difficulties in breeding both pearl millet and finger millet for low-resource conditions, though the methods for successful breeding are well known and adequate genetic variability is available. The difficulties arise from the complex genetic adaptation required to the many variable stresses, both physical and biological, which occur in low-resource production conditions, and the food quality attributes required in the grain. Local varieties usually contain excellent adaptation and good quality grain but are poor in resource-use efficiency in respect of grain production. For this reason, local germplasm must be used as parents in crosses with resource-use efficient stocks to breed higher yielding varieties. Breeding, at least the selection process, must be done in-country and involve on-farm conditions. Valuable back-up assistance and products of basic research can be provided to national breeding programs by international centers and CRSPS.

The main constraints to breeding millets in Africa are lack of trained scientists and technicians, inadequate facilities and operational funds for breeding and testing, slow communications with other scientists/centers of research and the long-time scale needed to make new varieties. There are only rudimentary seed multiplication and distribution systems, fertilizers are

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costly and in poor supply and extension sources inadequate in most African countries. Because many unknowns are involved, predicting results from breeding becomes speculative. However, generalities from elsewhere suggest that a 1% gain in yield per year of genetic origin can be expected. While there are practical limits to production in dryland tropical agriculture imposed by rainfall amount and distribution, a conservative estimate is that yield could be doubled in an African millet growing region in 20 years by a combination of new varieties and particularly be improved cultivation practices, provided that reliable local markets are maintainted so that producing surplus millet remains competitive with other enterprises available to the farmer.

2. Message. Among the major dryland cereal crops in African millets are of greatest importance in the lowest rainfall zones where food supplies fluctuate most. Assistance in the form of training, enhancing national capability for research, funding collaborative research with U.S. universities and international centers is needed to breed higher yielding varieties for these conditions. For breeding to have an early and significant impact, complementary agronomic research is required to improve production environments and rural grain markets must be stabilized.

DESCRIPTION

3. In sub-Saharan Africa 15.5 million hectares producing 8.8 million metric tons of food grains annually are sown entirely by low resource farmers to millets (FAO, 1985). Two species--pearl or bulrush millet [*Pennisetum americanum* (L.) Leeke] and finger millet [*Eleusine coracana* (L.) Gaertn.] both native to Africa, account for 95% of the production but are largely grown in different subregions and agroecological conditions. Other African millet species are either of minor importance, e.g. 'Iburua' or 'Fonio' (*Digitaria iburua*) in several west African countries--or of restricted local importance, e.g. 'Tef' (*Eragrostis tef*) in Ethiopia (145,000 tons/ann.). Seventy-five to

80% of the millet production is estimated to come from pearl millet (FAO reports do not distinguish between millet species) and most of the remainder from finger millet. Pearl millet is the staple cereal of the Arid and Semi-Arid Tropical (ASA) region from Senegal to the Sudan, where, on sandy soils there are no other major cereal food crop options. Pearl millet is also found in drier areas in eastern and southern Africa, but production here is about 1/5 of west Africa plus the Sudan. In contrast, finger millet is grown in eastern and southern Africa in the sub-humid tropical uplands (HST) principally in Kenya, Uganda, Tanzania, Malawi, Zaire, Zambia, and Zimbabwe (Rachie and Peters, 1977). In these areas, where rainfall is more consistent and evapotranspiration less, other cereal options, e.g. sorghum and maize, are available to low-resource farmers.

4. Benefits of Breeding. The benefits that millet breeding can bring to low-resource agriculture, are most evident in India--the other main region of millets cultivation--principally on pearl millet in the form of high yielding hybrids and disease resistant varieties. Yield increases at the farmer level over the last 18 years are about 20%, and perhaps half the annual Indian pearl millet crop of 11 million ha are now sown to hybrids and improved varieties. An aspect of significance for future genetic improvement in Africa is that the yield improvements in India were obtained from crosses between African germplasm and Indian breeder stocks--similar sources of variability also have great potential in Africa but are more difficult to exploit due to the higher disease and pest levels in Africa. Indian breeder stocks also have some derived African parentage but the breakthrough in breeding hybrids in India in the late 1960's came through initial use of U.S. genetic stocks carrying cytoplasmic male sterility discovered in Georgia, USA (Burton, 1958).

5. Technology of Breeding. The technology of breeding is substantially

different for the two millet species. Pearl millet is an early maturing cross-pollinating species on which a number of different breeding methods can be successfully used and two or even three breeding generations a year obtained. It can also be easily inbred, dwarfing genes and several cytoplasmic male sterility systems are known and heterosis is substantial.

Finger millet in contrast is almost entirely self pollinating and crosses can only made with difficulty. Varieties may be long maturing and two generations a year possible only with earlier types. Selection procedures are limited to pedigree based methods, however, the recent discovery of genetic male sterility in Uganda will permit easier crossing and the use of recurrent selection breeding methods. Cytoplasmic male sterility is yet to be discovered and the degree of utilizable heterosis unknown. Hybrid development in finger millet is therefore distant. With the exception of the program at Serere, Uganda, almost all breeding work (as distinct from selecting within landrace varieties = traditional or ancient varieties) in the tropics on finger millet has been done in India. For pearl millet, the bulk of the breeding and generation of genetic information as also been done in India but substantial contributions have also come from programs in several African countries, France and the USA. A good range of genetic variability is available for both species from the World Collections assembled by ICRISAT assisted by IBPGR. Finger millet germplasm is easier to maintain.

STATUS OF MILLET BREEDING IN SUB-SAHARAN AFRICA

6. Pearl Millet Varieties. Starting in the 1950's (earlier in Sudan, Tanzania, and Zimbabwe) there have been pearl millet breeding programs in a number of African countries (coordinated in francophone West Africa up to the mid-1970's by IRAT, France). Active breeding programs (where there is one or more national breeders entirely on millets) exist in Senegal, Mali, Burkina Faso, Niger, Nigeria, Sudan, Ethiopia, Kenya, Uganda, Tanzania, Zambia, and

Zimbabwe. Only in Uganda is there a significant effort on finger millet involving hybridization and selection.

A number of distinctly improved pearl millet varieties have been released, but there are few instances of wide-spread adoption by farmers although these varieties demonstrate 10-20% higher yields--a margin which would ensure immediate success in a developed country or India. However, many farmers in low resource situations in Africa have no means of properly measuring their yields, and cannot differentiate between variety effects of the 10-20% range and the normally larger yield fluctuations caused for other reasons within fields, between fields, and between years. The causes of why more productive varieties have not spread in Africa needs careful investigation as these may remain serious impediments to adoption of further genetic improvements. Socio-economists working at the farm-level have a vital role here. It is usually assumed that the causes derive from insufficient genetic superiority, but other possible causes--no supporting agronomic research, no quality seed services and especially the lack of stable markets--need evaluation as potential constraints to adoption of new varieties.

About 20 pearl millet varieties were released through collaborative research between IRAT and Senegal, Mali, Burkina Faso, Niger, and Cameroon between 1965 and 1978. These were mainly improved local cultivars showing up to 15% superiority over their parent varieties (Lambert, 1982). The most well known of these were Souna III in Senegal, M2D2 in Mali, P3 Kolo, CIVT II and HPK in Niger and M12 in Burkina Faso. The extent of adoption is not well documented and the degree of farmer to farmer spread not known. Because such seed multiplication schemes as there were, were small and not well implimented it is doubtful if more than 10% of a country was planted to the improved varieties. Possibly in Senegal the extent reached 20%. In Nigeria, variety ex

Bornu, similarly developed from local landrace material, was released after showing 14% yield superiority in interstate tests, but was never seriously multiplied. However, this variety was also of interest to other countries and has been released in Pakistan and may be released in western Sudan.

Since 1976, ICRISAT has participated in a regional pearl millet improvement project in west Africa and in 1982 established a regional pearl millet and groundnut center in Niger. Two varieties developed through collaborative ICRISAT/ISRA research were released in Senegal in 1982, being 14 and 20% higher yielding than Souna III (Gupta et al., 1983). These varieties have probably not reached more than 10% of the farmers but are currently under active multiplication. Varieties developed through similar collaborative in-country research with ICRISAT have been released in Cameroon and have led in tests in Burkina Faso and Niger. None, however, are more than 10-15% better than existing recommendations.

Products of the pearl millet breeding program at Serere, Uganda, are most widely grown but again there is a paucity of precise information on superiority at the farm level and extent of adoption. Serere pearl millet varieties are released and in cultivation in Sudan, Uganda, Kenya, Tanzania, and Botswana. This is a remarkable geographic range for material originating from one location. A line from Serere is the seed parent in use in several highly successful hybrids in India. Variety "Ugandi"--a derivative of Serere Composite 2--was selected and released in western Sudan with a 13-55% yield superiority over local varieties (Jain and Ahmadi, 1982). Serere 6A is widely grown in Botswana, but badly contaminated due to inadequate seed production and distribution. It is currently being reselected.

7. Hybrids. Single cross hybrids in pearl millet, using male sterile seed parents are the basis of vigorous private and semi-public seed industries in India. These and other types of hybrids have potential for Africa but there

are both technical and logistic constraints to be overcome before they can be used there (see later discussion). However, some information exists as to their potential in Africa. In numerous international tests the best hybrids were usually 10-15% better than the best varieties. In specific tests, IRAT report (Lambert, 1982) crosses between improved landrace varieties giving 27-59% more yield.

8. Finger Millet. Information on release and cultivation of improved varieties of finger millet in Africa is poor. Rachie and Peters (1977) report selections from landrace varieties released in Zaire, Rwanda, Uganda, and Malawi with yield increases in test of up to 25%. Zake and Esele (1984) mention a shortage of seed of released variety P224 in Uganda. Variety EK-1 is in prerelease multiplication in eastern Kenya.

9. Scale Applications of Breeding. Millet variety breeding work has been mostly aimed at the small holder and not for intensive agriculture situations which would be beyond the reach of the average dryland farmer. Some work was done in a Senegal project to produce dwarf varieties of a specific morphology deemed needed for high yield conditions. These conditions proved difficult to create and the varieties were insufficiently adapted to show this approach was a success. Merely inserting dwarfing genes into local varieties through backcrossing as tried by IRAT (Lambert, 1982), without attempting other changes, did not increase relative yields.

10. The current situation, therefore, is that though progress in millet breeding in Africa has been made (some substantial by comparison with rates of gain in developed countries), it has not had a widespread impact. Production is still by traditional methods using landrace varieties.

11. As a basis for planning breeding strategy it is, therefore, necessary to review the existing genetic and environmental constraints which currently and

in the future will limit millet grain production. A number of the factors itemized here (detailed in Appendix I) apply also to sorghum--Africa's other major native dryland food cereal. It is recognized that genetics and the crop's environment are but two components relating to one crop in the total agricultural production system.

12. Landrace (Traditional) Millet Varieties

Advantages	Disadvantages
-Well adapted to local physical and biological (pest and disease) stresses.	-Specialized localadaptation especially by daylength control of flowering often precludes wide adaptation.
-Vigourous, efficient at biomass production from limited resources.	-Resource use inefficient in grain production, i.e. harvest index poor.
-Grain qualities very desirable--adapted to consumer preferences.	-Some varieties relatively late maturing by daylength control of flowering, unsuited to high plant population levels.
-Well adapted to existing cropping patterns, including intercropping and to local length of season through daylength control of flowering.	-May contain unnecessary genetic impurities easy to breed out.

13. Major features of existing crop production systems for pearl millet in the Arid and Semi-Arid (ASA) regions south of the Sahara.

(1) Physical

- Rainfall limited in amount and distribution--likelihood of low rainfall total and midseason drought periods.
- However, storms can be intense with wind erosion preceding soil erosion.
- Sandy soils poor in plant nutrients, particularly phosphate.
- Soils very low in organic matter and CEC—tending acid.
- Soil resource degrading through the frequent cropping without soil conservation. Loss of savannah-tree protection.

(ii) Biological

- Numerous severe endemic pests and diseases (landrace varieties usually carry tolerance).
- *Striga* spp. (root parasites on cereals and legumes) devastating in places.
- Birds--residential and migratory (esp. *Quelea*).
- Storage pests--insects and rodents.

(iii) Cultural

- Most cultivation is by hand--low adoption of animal traction--consequently land surface cultivable per capita is limited and weed control a major problem (herbicides not feasible).
- Intercropping is common.
- Traditional fallow periods being reduced by demand for land.
- Almost no chemical fertilizer use--no attempts to increase soil organic matter.

14. The integration of environmental constraints, and the advantages and disadvantages of landrace cultivars, provide the following indications.

The probability of midseason drought (i.e. when plant growth is affected to the extent that final yield will be reduced) imposes a restriction on the amount of seasonal crop growth that can be scheduled i.e. it limits permissible planting density and fertilizer levels. This can be translated into the permitted total biomass which can be safely carried through the season to complete grain production. Soil conservation and improvement of soil moisture retention (e.g. through higher organic matter content, better weed control, etc.) can raise permitted total biomass levels as can, to some extent, plant drought resistance. Grain yields can also be increased by improvements in the plant's ability to partition the biomass it produces into grain (the so called harvest index--HI). Potential genetic improvements are substantial. Landrace varieties typically have HI's of 20% (15-25%) while high yield varieties (HYV's) are

40% or higher. Thus crop grain yields can be raised both by improvements in cultural conditions and through breeding to improve the crops yield efficiency. But the only major route open to higher grain yields when the biomass ceiling imposed by seasonal crop water availability is reached is by crop breeding.

15. The process of breeding varieties for low-resource agriculture needs care. To identify and recover the gene-complexes conferring stability of production, breeding usually needs to be done in situ in the adaptation zone concerned, since the mix of soil moisture and other soil effects, pests and diseases do not occur elsewhere. Also, many do not occur regularly at any given location, necessitating more careful and extensive testing. A regretful tendancy of many breeders in low-resource agriculture locations is to create atypical growing conditions on experiment stations where they can more easily detect genetic differences, forgetting that they are losing touch with the "real world" of the farmer. A basic requirement in breeding programs is a proper balance between creating appropriate genetic variability on the experiment station and sorting (selecting--not just final testing) it out in on-farm conditions. This may involve the breeder in spending 20% of his time working directly in on-farm situations, or better, collaborating in projects with agronomists and socio-economists who are developing and testing technologies in on-farm conditions.

16. Pearl millet in particular occupies a critical position as the staple food crop in the drought-prone Sahelian zone south of the Sahara in west Africa through to the Sudan. It has gained the status because it can give more reliable yields than other major cereals, particularly sorghum, in the prevailing conditions. Essentially in west Africa, the rainfall amount and reliability decreases from south to north, accompanied by soil changes from lateritic or loamy loess with some clay, to almost pure sand. Dominant cereal crops change in the same direction from maize, through sorghum to pearl millet.

There are no well defined boundaries between these crop zones partly due to local soil differences, and partly because early millet is often intercropped with full-season sorghum. Given an overall improvement in growing conditions and soil moisture retention, the "boundaries" between the zones where these three cereals are dominant will move north. But there will always be a northerly zone where, despite good soil moisture management and adequate fertility, pearl millet will remain the major cereal. However, even within the constraints of low rainfall amount and uncertainty of distribution, grain yields within the pearl millet zone can probably be doubled from their current levels of 600-700 kg/ha, through a combination of genetic and agronomic improvements. At present, low soil fertility and limited and untimely cultural practices are the major environmental factors restricting millet production, not crop water availability (Fussell et al., 1986). Yield potential is not a constraint in landrace varieties (which are capable of giving over 3 tons of grain/ha--Kassam and Kowal, 1975; Lambert, 1982), but their poor resource-use-efficiency for grain production (low harvest index) is.

17. Status within Major Development Agencies. Though assistance is being provided by CGIAR through ICRISAT for pearl millet breeding in Africa, this is insufficient in regard to the area cultivated and the importance of this species to the food security of many countries. For a period of 8 years (1976-1982) UNDP funded, via ICRISAT, up to 6 pearl millet breeders located in collaborative national programs in Senegal, Mali, Burkina Faso, Niger, Nigeria, and the Sudan where over 10 million ha are cultivated. ICRISAT, perceiving the need for more concentrated in-region research created a pearl millet and goundnut research center in Niger which became operational in 1982. This provides and coordinates backup research to national programs and integrates breeding and agronomic research. A pearl millet breeding project commenced,

funded by USAID through SACCAR at the ICRISAT Southern Africa Center in Zimbabwe in 1984. This now includes finger millet. The Serere pearl millet breeding program received strong assistance through USDA-ARS/USAID Joint Project No. 26 (the precursor of the current JP31 with SAFGRAD) from about 1963-1971.

Other agencies are/have provided funds for research on millet production which relate to breeding. Part of the current FAO Integrated Pest Management project in the west African Sahel is providing information on the control of pearl millet pests, diseases, and striga. EEC has funded, through CILSS, regional variety testing of several Sahelian crops including pearl millet. IBPGR has, of course, contributed to the future improvement of pearl millet, finger and other millets by coordinating the assembly, maintenance, and cataloguing of germplasm stocks at ICRISAT and funding some collective expeditions.

18. Costs of Millet Breeding. The financial costs of conducting millet breeding research are substantial and require long-term commitments though not as high as some more sophisticated areas of biological research and not high in comparison to many development projects. Breeding programs need to be located where there are other crop improvement scientists and have the financial and logistic resources to conduct large field programs and on-farm testing. Off-season nursery facilities are essential. Since new varieties once made can have far-reaching effects via seed, the potential benefits of investment into breeding research are very high. The costs of implimenting the resulting technology (consisting of multiplying the seed and getting it to the farmer--whichis commercially attractive itself)--are very low compared to other simple technology products such as fertilizer which involve larger volumes, additional costs for application and learning some new management expertise.

19. Negative Impacts. New varieties, if properly bred should have few

negative effects. New varieties should be of the type which can use but not require higher amounts of fertilizers/pesticides or build up existing disease or pest levels--since these lead to production fluctuations. Similarly, dependence on one new variety in a locality should be avoided. Hybrids have some potential negative effects since farmers need to get new seed each year. However, the plus side of hybrids is that they can provide sufficient financial incentive to attract private industry into supplying quality seed to the farmer.

20. Key Constraints. The key constraint to millet breeding is the technical difficulty of manipulating many genetically complex attributes in inconsistent environments. Numerous attempts bear testimony of the uselessness of trying to do this at long-range. The breeding--certainly the selection--needs to be done in-country and in real world farm conditions. Specially created environments may be needed to deal with severe specific constraints whose occurrence is unreliable--drought or a critical pest or disease.

Equally important constraints are, of course, insufficient trained scientists and their technicians, in adequate facilities and operational funds. For low-resource agriculture, a breeder is not trained because he has academic qualifications, though these are necessary precursers. A breeder only becomes proficient when familar with the target environment, the producers, the crop, and its uses.

APPLICATION OF OTA'S PRINCIPLES AND CONCEPTS

21. See Table 1.

POLICY ISSUES

22. In only a few countries is pearl millet the primary food cereal of the country--Senegal, Mauritania, Niger, and Chad--but there are many others with large regions where pearl millet is of major importance to the food economy and

where there is little opportunity e.g. through irrigation, of alternative food production. Finger millet is not as widely essential as pearl millet but, nevertheless, it represents a valuable asset to food production. Many African countries have little developed industry or exports to pay for food imports and it is imperative that they make the maximum use of their own food production resources. Many types of assistance are needed to develop these--training, institutional development, extension services, seed industries, product diversification, market expansion and stability.

23. Constraints. There are two distinct issues here--difficulties of conducting breeding (see paragraph 15), and constraints to the adoption of new varieties. The latter may be numerous and range from insufficient genetic superiority or grain quality, through to poor extension and seed services, but most of all because of poor and fluctuating markets. Small farmers will not produce surplus food crops unless there is a worthwhile market for them. Pricing policies and markets exist for the so-called cash crops e.g. cotton, groundnuts, tobacco, and there are similar needs for food crop surpluses. For food crops there are additional difficulties, of course, volume is larger and there are problems of deterioration in storage.

24. Cautions. The principle caution regarding new varieties is that they should not adversely affect the biological equilibrium between host (the crop) and pests and diseases. This can sometimes happen before the damage is noticed--as occurred with the first sorghum hybrids in Maharastra in India. These carried no resistance to the parasitic weed Striga, and now Striga levels are much higher (the seed persists 10 years in the soil) than they were traditionally. Striga is generally worse in Africa than Asia and the potential for this to happen through the careless release of a variety with insufficient resistance is greater. A further instance, regarding the grain midge, can be given--more obvious in sorghum than pearl millet. Main crop varieties in an

area are synchronized to flower and mature at the same time (often through control of flowering by genetic response to specific daylengths). In this situation, grain midge is not a problem. However, the unwitting cultivation of a sufficiently early variety can serve to increase the pest to a level that seriously damages nearby main crop varieties. Such potential problems need to be recognized and tested for. Sufficient on-farm testing will reveal deficiencies.

POTENTIAL OF MILLET BREEDING

25. Yield gains from breeding over the past several decades in major crops where breakthrough situations have not existed have varied, but a rule-of-thumb value is 1% per annum. These have mostly been obtained in developed agriculture situations. In Africa there are initial opportunities of faster rates of gain but given the constraints of rainfed low-resource agriculture (with no irrigation) breakthroughs, or green revolution situations, are not to be expected. Currently, quite properly, the concentration is on variety development because of better stability of yield and ease of multiplication. However, opportunities will arise when hybrids can be used and if so a 10-15% increment in yield potential will occur. However, as discussed elsewhere (Andrews, 1986a) pearl millet hybrids in Africa should not involve cytoplasmic male sterility because of ergot susceptibility, and should not be of the inbred x inbred type because of their known vulnerability to disease pressures. However, hybrids between varieties, or variety x line hybrids exploiting the natural flowering behavior of pearl millet to make a sufficiently high percentage of hybrid seed are quite feasible. Adoption of hybrids by farmers would require farmer education and reliable seed multiplication and delivery systems.

New varieties need to be supported by a package of improved cultural practices devised, like new varieties, from the base line of traditional practice. If this involves intercropping, which is frequent with pearl millet growing, then the improved package should be applicable to intercropping. As discussed in the OTA intercropping paper (Andrews, 1986b), varietal improvements are likely to be expressed in the intercropping as well as the sole cropping situation. Selecting between a number of variety options for a given intercrop might be as far as it is feasible to go, since breeding specifically for an intercrop situation is an added difficulty of possibly limited application.

Though investment into plant breeding needs to be of a long-term nature, the payoff, because of the multiplication effects through seed increase, are very high relative to other means of increasing production, e.g. by fertilizer use.

26. Applications of Advanced Technologies. The type of plant breeding activities needed for low-resource areas are of a production line nature--they rely on volume and draw on basic information or base materials generated from other disciplines and elsewhere to put together new varieties. Technology which can speed up and make the production line process more reliable is appropriate--laboratory and field research equipment, computers and statistical software, rapid information aquisition and transfer. Determining grain qualities connected with consumer preference requires well-equipped laboratories and as far as possible should be conducted through collaborative research.

Sophisticated biotechnology research is expected to have an impact on millet productivity, but it needs to be done at centers for basic research and then simplified or transformed so that it can be used in production breeding. Wide crosses are needed in pearl millet to obtain valuable traits from related species--immunity to downy mildew from elephant grass for instance. Tissue culture, anther culture, protoplast fusion, all have applications. Research on the biochemical and physiological nature of the relationship of the cereal to the *striga* parasite is needed if any real progress is to be made in controlling this pest. Research is needed on how to more easily make hybrids (through chemical hybridizing agents) or even perpetuate them clonally through asexual seed. Funding for this type of advanced research, however, needs to be located at universities and centers with the necessary expertise and aimed at producing simply applied techniques or genetic stocks which can be used in production plant breeding programs.

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List of Acronyms

CGIAR — Consultative Group for International Agricultural Research

CILSS — Comite permanent InterEtats de Lutte contre la Secheresse dans la Sahel

EEC — European Economic Community

IBPGR — International Board for Plant Genetic Resources

ICRISAT— International Crops Research Institute for the Semi-Arid Tropics

IRAT — Institut de Recherches Agronmiques Tropicales et des cultures vivieres

ISRA — Institut Senegalais de Recherches Agricoles

SACCAR — Southern Africa Center for Cooperation in Agricultural Research

SAFGRAD --Semi-Arid Food Grains Research and Development--JP 31 USAID/OAU

Appendix I

Rationale for millet breeding needs vis-a-vis landrace variety attributes and environmental constraints of low-resource production systems.

The general objectives for breeding food crops including the millets for low-resource agriculture are reviewed below (as they differ in some respects to breeding for developed country situations) and since they provide basic information as to the type of assistance and support needed for breeding research in developing countries.

The genetic constitution to give consistent (or stable) production from year to year and place-to-place is required rather than ability to respond to high fertility conditions (the latter being the case with the so-called green revolution irrigated wheat and paddy rice varieties). The creation of such high fertility growing conditions will not normally be realistic in rainfed non-irrigated low-resource agriculture because of the risk of drought, pest and disease problems though, because of micro-relief and better soils, such as in valley bottoms, rational localized use of higher than normal fertility conditions will be possible. However, some general improvement in plant nutrient supply (through crop rotation with legumes, better soil organic matter content, and some mineral fertilizer use) is absolutely essential to complement genetic improvement in rainfed non-irrigated low-resource agriculture and vital to preserving and enhancing the crop production resource base for the future. This is perhaps one of the more difficult and needed areas of research in Africa.

Landrace varieties (i.e. those that have developed over centuries of farmer selection) have accummulated high levels of genetic resistance or tolerance to both physical stress conditions (drought, low nutrient supply, unfavorable soil pH) and many biological stresses (pests, diseases, weeds) which confer good stability of production. Most became locally specialized over time and do not show wide adaptation. Desirable grain qualities were usually maximized and these remain a major breeding consideration.

Landrace varieties are remarkably efficient in producing total plant biomass from limited resources, but relatively poor at converting this into the product most needed--grain. (A portion of the crop residues--stems, leaves--are used in low-resource agriculture, but are never as important as the grain.) Landrace varieties are often categorized as poorly responsive to fertilizers. In the strict sense, this is rarely true. A more correct statement is that they are less responsive in terms of grain production. Usually landrace varieties are, at low and intermediate levels of fertilizer application, superior to high yield varieties (HYV's) in terms of biomass production response and thus are excellent parents in a breeding program. HYV's as bred in developed countries, are much superior in converting a larger part of the biomass into grain and may be termed resource-use-efficient in respect of grain production. However, in low-resource stress conditions, introduced HYV's without local adaptation usually yield less grain than landrace varieties.

Varieties may differ in their crop water-use efficiency (and intercrops may be seasonally more water-use efficient because of better temporal exploitation). Landrace varieties can usually more efficiently use (in respect of units of biomass produced per unti of water) the total soil water available in a season because their slowly developing but eventually extensive root systems can finally extract more water and because of better control of water expenditure on a crop basis. Similar arguements apply to the obtention and use of limiting plant nutrients from the soil. Large vegetative landrace plants may remobilize nutrients, especially nitrogen, during growth and use them eventually in grain formation. However, the variety differences in crop water use are considerably less than the magnitude of differences in the harvest indices (HI i.e. the percentage of the total dry matter made into grain) between the landrace varieties, typically 20%, and HYV's, with HI's of 40% or better. Thus, a landrace variety needs considerably more water than a HYV to produce one unit of grain. The same applies to nutrients.

In any locality there is an upper limit to the biomass production possible depending on the average probability of periodic crop water availability over the season. The penalties for creating a crop-water demand which exceeds supply in any period of the growing season can be severe--even amounting to crop failure. At present, however, low soil fertility and limited and untimely cultural practices are major factors restricting millet crop production, not crop water availability. While genetic improvements of variety resource-use efficiency, given the proper adaptation background (harder for the lower yielding environments) are complementary to other agronomic improvements, breeding more efficient varieties will be the only route to higher grain production when crop water availability becomes limiting.

Gene complexes for resource use efficiency for grain production are hard to find in landrace varieties, but have been built up through several decades of breeding, usually in HYV's bred in developed countries (the best examples exist in maize and sorghum in the U.S. but can be seen in pearl millet in India). The primary objectives for breeders in low resource conditions are to combine the landrace yield stability traits with the resource-use efficiency for grain production (usually best obtainable from HYV genetic stocks from elsewhere) and, if possible, to widen the scope of adaptation. As may be deduced there are numerous adaptation regions in Africa and single varieties cannot be expected to trancend major adaptation boundaries--nor would this be desirable from the aspect of genetic vulnerability. Because of the important contribution of heterogeneity in stabilizing production in low-resource agriculture, the breeding of only one variety for a locality should be avoided.

The cross-pollinating system of pearl millet permits internal genetic heterogeneity to be retained within each variety--a highly visible feature in any landrace variety. This also has definite implications for the type of hybrid which would be suitable--inbred x inbred being the least desirable. Internal variety heterogeneity is not possible with finger millet, though variety mixtures are.

Table 1. Application of OTA's principles and concepts to millet breeding.

What needs to be done	How to do it	Who should do it	What limits it
Principle A--Components in African Low-resource Agriculture			
Breeding strategies must meet ecological, social and economic demands.	Breeders must understand how their varieties can satisfy ecological, social and economic requirements.	National breeders best, but when national manpower is insufficient, staff of assistance agency working in country/region	Research staff numbers. Time constraints of plant breeding--long-term but incremental process.
Principle B--Linkages in African Low-resource Agricultural Systems			
Crop improvement should be part of the total agricultural production system, and linked externally to similar breeding locations.	Ensure plant breeders work with other scientists and extension personnel in crop production, and socio-economist. Increase agency assistance and collaboration with international centers.	Those administering crop research should ensure interdisciplinary research is planned and executed. Breeders in particular need interdisciplinary support.	Traditional within-discipline research attitude. Insufficient contact with millet breeders elsewhere and up-to-date knowledge of methodology successful elsewhere.,
Principle C--Low-resource Farmers and Herders Responses			
Primary goal of breeding is to maintain or improve levels of yield stability while increasing grain yield potential.	Ensure local germplasm sources are incorporated into breeding process along with high yielding stocks. Imperative selection process incorporates repeated exposure to major factors contributing to yield instability.	Breeders working in situ both on experiment stations and on-farm. Scientists in international centers/CRSPS should seek dedicated collaborative projects.	Staff numbers, both scientific and technical, insufficient operating funds, difficulty of conducting on-farm experiments. Sometimes access to appropriate exotic high yielding stocks.
Principle D--Use of Local Resources			
Use local germplasm, local environments and farmers and consumers opinions in breeding.	Obtain local germplasm collection for use in crosses. Define breeding goals and product (grain) quality requirements with farmers and consumers. Use	Breeders in collaboration with other crop improvement scientist, socio-economists, farmers, and consumers.	-Low numbers of trained staff. -Lack of expertise in defining realistic plant breeding goals for low-resource conditions. -Cost of comprehensive testing. -Access to and maintenance of

Table 1. Application of OTA's principles and concepts to millet breeding (continued).

What needs to be done	How to do it	Who should do it	What limits it
Principle E--Heterogeneity of Low-resource Agriculturalists			
Maintain traditional principle of genetic heterogeneity of varieties to contribute to stability of production and serve consumers various needs.	Breed different varieties to serve different needs. Breed more than one variety for each locality. In pearl millet, avoid excessive inbreeding.	Breeders.	-Number of varieties required. -Breeding methods which minimize inbreeding require more operational resources.
Principle F--African Women Play a Key Role in Low-resource Agriculture			
Involve women in determining breeding goals particularly on food preparation aspects.	Ensure women participate.	National staff.	-Understanding of need to involve women. -Number of women candidates for training.
	Increase training of women in crop improvement and home economics.	Assistance agencies with with national staff.	
Principle G--Sustainability of Systems			
New varieties should not degrade biological production resource base and should incorporate existing natural pest management factors.	-New varieties should not require practices which degrade resources. -Should fit with intercropping sys tems where practiced. -Should not build-up through insufficient resistance) of pest, disease and especially striga in the system.	Cropping system and pest management scientists working with breeders	Staff numbers and training. Insufficient knowledge of what host/pest relations exist in in local production systems.
Principle H--Local Participation			
Maximize local participation.	Breeding for local adaptation requires participation of national staff both men, women, farmers, and consumers if is is to be successful.	Local scientists working with farmers and consumers helped, if necessary by assistance agency staff working locally.	-Lack of trained staff. -Insufficient contact of scientific staff with farmers and consumers. -Insufficient operational funds, facilities, and transport

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LOW-RESOURCE AGRICULTURE IN AFRICA

OTA Technology Paper Series: Maize Breeding

by

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Maize Breeding for Low-Resource Farmers in Africa

1. If current trends continue, by the year 2010 the food situation in Africa will be worse than at the height of the 1983/85 famine; by that time, all but four countries will be net agricultural importers, and cereal self-sufficiency will fall to between 45 percent for West Africa and 65 percent for Southern Africa. Yet, numerous farm trials and case studies indicate that by employing currently available technologies the average yields of cereals in areas with relatively stable rainfall could in a short time be doubled in many farming systems. There are two key technologies available now by which low-resource farmers can significantly effect production gains: increasing soil fertility; and adoption of improved plant varieties selected for African conditions together with improved production practices (FAO, 1986a).

2. Maize breeding involves the mating of two parent plants, followed by extensive testing of the offspring to determine those that are superior, by some standard, to both parents.

At the time Columbus set sail, maize yields in the New World were about 1,000 kilograms/hectare (kg/ha) - a yield level almost identical to that of Africa today. In contrast, current maize yields in the U.S. Corn Belt average about 10,000 kg/ha. This tenfold increase can be attributed to maize breeding that capitalized on response to inputs (fertilizers, herbicides, pesticides, etc.), improved husbandry practices, and on the scientific breakthrough of hybridization.

The USDA estimates that, worldwide, about 75 percent of the growth in per capita food production from 1950 to 1980 resulted from the use of improved technologies, with the remainder coming from an increase in land being cultivated. From 1961 to 1981, world grain yields increased from 1460 to 2149 kg/ha, however grain yields in Sub-Saharan Africa were, in general, stagnate at 849 to 969 kg/ha (CICHE, 1986).

Eighteen countries (seven in Africa), with a combined population of 213 million people, rely on maize as their most important staple. Given that cereals (primarily maize) account for 46 percent of the major staple foods in an African's diet (FAO, 1984a,b), improvement in both the quality and quantity of maize produced in Africa is essential.

From an ecological point-of-view, maize breeding has great potential benefits because the maize plant is relatively responsive to inputs and management, and its architecture allows it to be grown in association with many other crops. Moreover, maize breeding is a particularly versatile approach to increasing productivity because a breeder can concentrate on one or more desirable characteristics ranging from resistance to pests and diseases to response to inputs. Maize breeding, in general, is not dependent upon high technology. Rather, it requires: (1) trained personnel; (2) a source of germplasm; and, (3) a modest research budget.

Where the division of labor is gender-related, maize breeders can readily incorporate the differing clientele requirements in a breeding program. In Africa, when breeding a maize variety used primarily for home consumption (often produced by women), the breeder would probably concentrate on yield stability (not a disaster in a bad year and not superior in a good one), storage characteristics, and grain quality. When breeding a maize variety for cash generation (often produced by men), the breeder would probably concentrate on responsiveness to management and inputs.

Maize breeding can also be tailored to meet the institutional capabilities of a region or a country. Because not all countries have the trained personnel and/or research budget to mount a mature maize breeding program, they can bring in improved maize varieties from IARCs, regional centers, or private seed companies. Following extensive testing under farmers' management conditions, it is possible to identify those varieties best suited to meet the agroecological, economic and social requirements of the country.

According to the FAO (1986a), there is limited scope for expansion of cultivated area in Africa. Given that fact, farmers must improve the per area yield of their major food crops in order to release land for income generation from the growth of cash crops.

3. a. Currently, only 10 percent of the land devoted to cereal production in Africa is planted with improved varieties. The main reasons for this include: the lack of suitable varieties; inadequate seed production organizations; and/or inadequate seed distribution capabilities (FAO, 1986a).

The above, however, is, a generalization that does not hold true in those countries where there is sufficient infrastructure, incentive, and inputs that favor the use of improved varieties of maize. Notable exceptions are Kenya, Nigeria, Swaziland, Zimbabwe, and, more recently, Zambia. The Kitale Project in Kenya is often used as an example of how maize breeding dramatically increased maize production. Nigeria is making excellent use of disease-tolerant maize materials developed by the International Institute for Tropical Agriculture (IITA), and has mounted a nation-wide program for increasing maize production through the use of hybrids. Forty percent of all maize seed planted in Swaziland in 1985 was improved seed produced in-country through a seed multiplication project, and Swaziland now exports maize seed to neighboring countries (FAO, 1986a). Zimbabwe has an excellent maize breeding and seed multiplication program. SR52, a Zimbabwe hybrid, has long been the standard of excellence in the seasonally humid agroecological zones of East Africa. There has been a high acceptance rate by farmers in Zambia of maize hybrids that were technologically- and socioeconomically-verified by the on-farm research program.

b. The major donor support for maize breeding in Africa is indirectly through bilateral projects and directly through the International Maize and Wheat Improvement Center (CIMMYT) and IITA. CIMMYT has recently intensived its efforts in East Africa by establishing a regional maize center in Zimbabwe.

c. With the exception of the breeding work at IITA for resistance to Maize Streak Virus, maize breeding in Africa has generally been aimed at those farmers who have access to, who can afford, and who can make use of yield enhancing inputs. CIMMYT has done extensive breeding for improved grain quality but this has yet to make an impact in Africa. Some preliminary breeding work being done at IITA for resistance to a parasitic weed portends the possibilities of scale-neutral maize breeding which has applications to all farmers. Resistance to stalk borer, for example, would have application to both low- and higher-resource farmers.

d. Maize improvement research is, however, meaningless if there is not a viable seed industry in either the public or private sector. Few African countries have adequate seed industries that can handle, process, store or market seeds. Moreover, few have mechanisms to test improved varieties in farmers' fields, and adequate seed laws are largely non-existent (FAO, 1986b).

Table of Application of OTA's Principles and Concepts
MAIZE BREEDING

Principle A: Systems Approach

what needs to be done	how to do it	who should do it	what limits it
-develop maize breeding programs that integrate ecological, social, economic and institutional components	-multidisciplinary research teams	-IARCs and national research and extension services	-lack of trained personnel
	-farmer participation in research	-IARCs and national research and extension services	-lack of funds
	forge stronger linkages between research and extension	-national research and extension services	-national institutional schism between research and extension

Principle B: Linkages

what needs to be done	how to do it	who should do it	what limits it
-forge stronger linkages among IARCs, regional institutions and national research and extension services	-donor assistance tied to linkage development	-IARCs, regional and national technology development and dissemination institutions	-parochial attitude of national research and extension services
-increased technical and managerial capabilities of national research and extension specialists	-donor assistance targetted for human development	-IARCs and national and international universities	-donor's preference for quick rather than sustainable development projects

Principle C: Minimizing Risk

what needs to be done	how to do it	who should do it	what limits it
-characterize risk avoidance strategies used by farmers	-biological, economical and sociological studies	-national research and extension services and universities	-lack of funds -lack of trained personnel
-assess potential technologies using degree of risk as a criterion	-farmer participation in evaluation of technologies	-national research and extension services	-lack of funds -difficulty of assigning a degree of risk to a technology
-farmers are provided incentives to produce along with new technologies	-improved price policy	-donors and national institutions	-perceived by national government to maintain low food prices
	-long-term credit for those technologies requiring time for benefits to accrue	-national institutions	-lack of funds -perception by national governments that agriculture is not a good or safe investment
	-crop insurance	-national institutions	-national capacity -ignorance of farmers -reluctance by national institutions and farmers to accept something new

Principle D: Employing Local Knowledge and Resources

what needs to be done	how to do it	who should do it	what limits it
-collect and characterize local maize germplasm	-systematic germplasm collection effort	-FAO, IARCs and regional centers	-lack of funds -lack of trained personnel
-incorporate desirable local germplasm into breeding programs	-describe local germplasm that may alleviate production constraints	-IARCs and regional centers	-time to improve relatively wild germplasm -short time frame of most development projects

-develop regional germplasm exchange programs	-develop regionally-funded maize improvement centers	-donors and regional countries	-reluctance of donors to fund regional programs -reluctance of countries to cooperate on a regional basis
-characterize local practices and improve those that have merit to increase production	-biological, economical and sociological surveys	-national research and extension services and universities	-lack of funds -lack of trained personnel -protracted time frame
	-farmer particpation in research	-national research and extension services and universities	-lack of funds -perception that farmers' practices have no merit

Principle E: Heterogeneous Nature of Low-Resource Farmers

what needs to be done	how to do it	who should do it	what limits it
-determine those factors that can be used to characterize the technological needs of different groups of farmers	-biological, economical and sociological studies	-IARCs and national institutions	-lack of funds -lack of trained personnel -recurring requirement because farmers are dynamic
-verify that those factors previously characterized will require different maize technologies	-farmer participation in research	-national research and extension services	-lack of funds -lack of currently available alternative technologies
-develop research programs geared to solve production constrainsts of differing clientele groups	-farmer input in the development of research programs	-national research and extension services	-lack of funds -lack of trained personnel

Principle F: Role of Women

what needs to be done	how to do it	who should do it	what limits it
-characterize technologic-differences between sexes	-multidisciplinary research teams that include women	-national research and extension services	-lack of funds -limited number of women in research and extension
-develop maize varieties that satisfy the special requirements of women farmers	-female farmer participation in the development and verification of new maize varieties	-national research and extension services	-lack of funds -social constraints

Principle G: Sustainability

what needs to be done	how to do it	who should do it	what limits it
-develop national institutions that can sustain the environmental social and economic aspects of a maize improvement program	-orient development assistance projects to human and institutional development	-donors and national governments	-donors unwilling to make the long-term commitment required

Principle F: Local Participation

what needs to be done	how to do it	who should do it	what limits it
-give priority to the institutional aspects of development assistance	-develop institution building projects	-donors and national governments	-time required for institutional development
-countries develop the capacity for making policies to strengthen institutions	-use development assistance to develop national capacity for policy-making	-donors and national institutions	-national institutional weakness.

4. b. The first priority in Africa is to raise the productivity of cultivated land on a sustainable basis. It is impossible to technologically turn back the clock and still feed the increasing populations of most African countries. Although ecologically sound, few traditional farming systems can support large populations, therefore, land and labor productivity must be increased through the use of more external inputs. It is of particular significance that improved varieties do not necessarily require a high level of inputs. They are, however, very responsive to improved management practices such as timeliness of planting, weed control, fertilizer, and increased plant populations (FAO, 1986b).

While not discounting the opportunites that exist for building on some local practices and using locally adapted germplasm, there seems to be little opportunity to build on those practices that suppress yields such as inadequate weed control, untimely date of planting, etc. Practices such as these must be changed if production is to increase. Also, although usually adapted to poor management practices as well as to the local pest and disease complex, local (unimproved) maize varieties are relatively nonresponsive to improved management practices.

Given the gravity of the food situation in Africa and the general understanding that little gain can be made with improved maize varieties without accompanying improved management practices, in the near-term the highest return to maize breeding investment in Africa is through a two-pronged strategy of: identifying improved varieties that have performed well under similar agroecological and socioeconomic conditions; and, extensively screening these varieties under local conditions with the goal of making those best adapted available to local farmers.

In general, local unimproved varieties have less than one-half of the yield potential of improved adapted varieties under good, not high, management practices. Discounting the possibility of serendepity, if a breeder in a developing country structured a maize breeding program totally upon improving local varieties, it would take a number of years before the local varieties were near the performance of improved varieties that were available at the beginning of this breeding effort - there is no guarantee that improved varieties made up of local material would ever be equal. From the point-of-view of donor agencies, local governments, local farmers, and the dismal food predictions for Africa, the latter approach has no logical basis as a breeding strategy for a national program.

The foregoing is not to imply that local maize germplasm would not be useful in a breeding program. This would, however, require extensive characterization of the germplasm; slow and reasoned introgression of the desirable local material into improved material; thorough testing to identify superior offspring; and, most of all, time (there is no way to reasonably predict the time required for a payoff from this approach). Most national breeding programs do not have the budget and trained personnel that this would require, and they certainly do not have the time. This type of effort is best left to those agencies such as IARCs, regional centers and those countries that have the trained personnel and a long-term budget and mandate.

In terms of gender issues as they relate to maize breeding, these seem rather straight forward. Breeders must take into account the requirements of all their clients. The first step in developing a breeding program is, therefore, to identify those requirements. To do this, farmers - both men and women - should be full participants in developing research efforts. In addition, to enhance these efforts, more women should be recruited, trained and integrated into national research and extension programs.

The best opportunity for increasing production of maize grown by women farmers is not through maize breeding alone, but in conjunction with improved maize management practices that are developed to satisfy the special requirements of women farmers. Most studies indicate that women's family responsibilities compete with farming requirements. Appropriate labor-saving technologies such as improved hand tools or even herbicides for timely weed control offer great potential because the best improved maize variety in the world will do little better than the worst local variety if weed control is inadequate.

5. a. One only need look at the phrases in vogue in USAID over the past ten years - "Technology Transfer", "Farming Systems Research", and, "Institution Building" to name a few - to realize that there is neither a comprehensive understanding of the agricultural development requirements for Africa nor a long-range strategy to effect the development process. To exacerbate this problem, USAID in recent years has eliminated nearly all

technically qualified biologically-oriented agriculturists from its ranks. Currently, USAID has an unbalanced staff favoring economic and social scientists. This has resulted in an inadequate mix of disciplines that are necessary to develop sound agricultural development policies and programs.

b. Donor agencies should develop national and regional capacity for sustained research (be it maize breeding, animal health or processing of food crops). This requires trained people and a commitment to research. The latter is referred to as institution building in development venacular. Unfortunately under some donor's strategy, development efforts are in the form of research projects which are of transitory value because little is left behind after the project is completed. USAID's average development project, for instance, is often too short in duration to do more than serve as an introductory phase. Institutional development requires a long-term commitment if it is to be effective.

c. The requirements for effective agricultural development have been defined in many studies and reports. These can be boiled down to: (1) incentives to produce; (2) identification/development of appropriate improved technologies; (3) dissemination of the improved technolgies; and, (4) a guaranteed access to inputs required in support of the improved tecnologies. Using a biological law of the minimum, whichever of these agricultural development ingredients is the most limiting will have the most profound effect on production. It follows then that maize breeding cannot be looked at in isolation from a development point-of-view.

With this as a point of departure, the following areas require emphasis from donor agencies to fully exploit the potentials both of maize breeding and effective agricultural development in Africa.

1. Immediate gains from maize breeding are most likely to be realized by national programs drawing upon finished or near-finished improved materials from international and regional, or other national, maize improvement centers. Donor agencies must encourage: (i) national programs to develop effective linkages with these programs; and (ii) international and regional centers to factor national requirements and germplasm into their maize development efforts.

2. International agricultural development, particulary technical aspects such as maize breeding, requires long-term donor support based upon realistic development strategy. USAID should be encouraged to recruit more biologically-oriented agricultural scientists in order to develop projects that are targetted at solving both biological and socioeconomic impediments to productivity. Additionally, USAID should develop, fund and implement agricultural development projects only after conducting a comprehensive biological, economic and social analysis such as those conducted by the World Bank and FAO.

3. Sustainable national agricultural development,

that include activities such as maize breeding that warrant a long-term commitment, requires national institutions that can: develop, implement and execute priority research and extension programs; develop policies that reflect that country's comparative advantage; and, provide incentives for production. Donor agencies should abet national institutional development by placing a higher emphasis on training of nationals than on provision of expatriate technical assistance to execute programs.

6. a. Between 1980 and 1983, more than 70 new maize varieties from the CIMMYT coordinated network were released in 22 developing countries. The additional production from the use of these varieties is estimated at about one million tons. Less than 20 years ago, no improved maize varieties were planted in Kenya, however, by 1980, 370 thousand hectares were planted to improved hybrid maize - 94 percent of this was on low-resource farms (Brady, 1984). The FAO (1986a) estimates that Kenyan and Zimbabwean maize varieties are widely adapted and that the area devoted to their production could be doubled in Sub-Saharan Africa.

Given that improved maize varieties exist in international and national programs that could dramatically increase maize production in Sub-Saharan Africa, and given that commercial grain imports and food aid in Subsaharan Africa totaled 21.5 million tons even before the 1983/85 drought (Brady, 1984), an intensification of the effort to import improved varieties and to test them for adaptability should be accorded high priority and increased donor support especially in the seasonally humid areas. Additional support in this effort is available from private seed companies that have developed hybrids that are well adapted to both favorable and unfavorable growing conditions in this part of the world.

b. There is ample evidence to indicate that low-resource farmers in Africa are responsive to incentives to production and to improved adapted technologies. As with U.S. farmers who are generally very conservative, there is reason to believe that the adoption rate of improved maize varieties will be slow at first because some risk is involved in the form of purchased seed and the inputs required for improved varieties to express their production potential. As the more cautious farmers observe the benefits that their more daring neighbors realize from the use of improved varieties, and as governments make the required inputs more readily available, adoption of improved maize varieties will be multiplicative rather than additive. This will require the patience of donors and host nations if the potentials of improved maize varieties are to be realized.

c. As cited above, improved maize varieties require a modest level of inputs and improved management practices. Unless these inputs are available at a price that warrants their use, and unless improved management practices are within the capabilities of low-resource farmers and made part of the extension message relating to the use of improved maize varieties, there is little need for a nation or a donor to invest in maize breeding for low-resource farmers.

d. The cutting edge of research for maize breeding in Africa is national capacity to test the improved varieties under farmers' conditions in order to evaluate their biological, economic and social suitability.

e. There seem to be some potential for biotechnology in maize breeding especially as it relates to stress tolerance. This approach is beyond the capabilities of most national programs and of the IARCs. The exploitation of biotechnology for maize breeding in Sub-Saharan Africa will require IARCs and/or national programs to develop effective linkages with the more basically-oriented research institutions such as U.S. Land Grant universities.

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DRAFT

OTA TECHNOLOGY PAPER: SORGHUM BREEDING

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DRAFT

1. Throughout the arid and semi-arid areas of Sub-Saharan Africa sorghum is either the most or second most important cereal grain, sharing importance with the cereals commonly called millets. Sorghum evolved under stressed conditions in North-Eastern Africa some 2-4000 years ago, and has the inate capacity to survive within low-resource agricultural systems. It is the primary source of dietary energy for many of the regions poorest people. In general, farmer yields in the region average 500 to 1000kg/ha, yet the crop has the genetic potential to produce at least 15000kg/ha on a commercial scale, as has been shown in both Africa and Latin America. Given this genetic potential, and Sorghum's inherent ability to product a crop under very restrictive conditions, sorghum breeding has the potential of producing a technology (improved seed) which can dramatically improve farmers lives without requiring cash for other inputs, or substantially increasing the risks faced by farmers in their struggle with a harsh environment. While sorghum has the ability to perform under severe stress, under the most severe conditions of heat, drought, poor fertility or management even it will fail.

2. Sorghum breeding is an art as old as the crop, but rather young in terms of a modern science. The germplasm base is extremely broad, but still vastly underutilized, and since sorghum is of African origin, Africa stands to benefit greatly from any and all research. In its broadest terms, sorghum breeding is a process whereby lines of different desirable characteristics are crossed, and the desired combination of characters is then sought in the offspring. Many selection techniques can be used, but ultimate objective is to produce a new variety which is more useful to the farmer and/or consumer, whether that means more yield, better protein quality, superior storage quality or increased drought tolerance.

3. Genetic improvement of plants has proved itself to be of great benefit to the farming sector as well as the economic and social structure of a country. The development of maize hybrids in the U.S. played a major role in the change of a agrarian society into an industrial one by providing a means for half the nation to move off the farm and into an industrial economy. The same kind of technology in sorghum and other crops has set the stage for the present situation of surplus and emigration from agriculture. In Sub-Saharan Africa, the same potential exists with the proper use of breeding technologies. Where sorghum is now (or should be) the predominant crop, yield increases of sufficient magnitude to begin these kind of changes are possible. This can be done initially without significant changes in the agricultural system, but the results on the social and economic systems will be substantial.

4. In general, the adoption of improved varieties of sorghum in Sub-Saharan Africa has been very slow and uneven. In East Africa (Kenya, Uganda and Tanzania) 5-10% of the sorghum grown is 'improved', most of that derived from the Serere, Uganda program, and dating from the 1960's. Most of that is grown for the commercial market, and local (traditional) varieties are grown for home consumption and local markets. Zimbabwe has had a different experience, as has Sudan, where the adoption of hybrid varieties of sorghum has been substantial. In West Africa, the situation is perhaps more bleak than elsewhere. Except where irrigation is used, adoption of new varieties is almost nil. "In the 'sorghum belt' of Africa, so little progress has been made in yields that there is serious question if adaptable improved technology is available. If it is, the farmers have not yet adopted it at all." (Lang, 1981). In those areas where improved varieties are being used, the technology is still very much scale dependent, as the only really successful improved varieties are hybrids (e.g. Hageen Durra-1 in Sudan), and small farmers have not yet been able to incorporate this technology level into their low-resource systems.

5. The status of sorghum breeding programs within the major development assistance organizations has taken a significant jump since the African drought of 1981-85. It has become evident to many that drought tolerant crops such as sorghum must have increased emphasis if Africa is to become food self sufficient. USAID, FAO, the World Bank and others are increasing their emphasis on sorghum in Sub-Saharan Africa. Even so, this

emphasis does not yet match sorghum's importance in the region.

6. The costs of a successful sorghum breeding program in the region will fall mainly in two areas. Increased emphasis on research and extension will be necessary over a long time span to accomplish the desired changes. The actual costs are not large, but the committment must be for 20+ years. At the back end, costs will increase for storage facilities, roads, markets, etc to accomodate increased production. Negative impacts will be minimal if sorghum breeding efforts begin at the farm level, and move up, rather than working from "modern" technology down. This implies that stability will be decreased in the system only after farmers incomes have reached a point where some risk is sustainable. Labor demand should not change in the short-term, but may well change in the longer term as incomes rise.

7. Key Constraints to Improved Sorghum Production through Breeding.

- Lack of local government support for research and ext.
- Poor understanding of the farming system by research
- Women farmers not involved in research/ext efforts
- Labor constraints during weeding, bird scaring
- Lack of patience by donors (i.e. projects too short-term)
- Poor incentives for production
- Lack of organized markets outside of the production areas
- Poor infrastructure to move inputs/outputs
- Inadequate germplasm base for genetic improvement
- Inadequate understanding of food quality factors

8. Although sorghum is usually thought of as a crop of arid and semi-arid areas, it is also very important in certain areas of the region where moisture is not a limiting factor. It is important in the highlands of East Africa from Ethiopia to Burundi and Rwanda, as well as in the semi-humid areas of Western Kenya and Uganda, and in areas of the Guinea Savanna in West

Africa. Except for the obvious difference that drought tolerance is not a most important feature of the sorghums in these areas, the other problems and possibilities are very much the same in all the growing areas across the region. For that reason, these different zones will not receive different treatment in the remainder of this document.

Application of Principles and Concepts

Principle A: Systems Approach

What needs to be done	How to do it	Who should do it	What limits it
- Increase knowledge of local ag systems, and their interactions with markets and national priorities	- Expand role of extension to study local systems - Involve ag scientists in determination of local needs and issues.	- Extension service - Ministry res scientists - Universities	- Lack of awareness that need that need exists - lack of funds - top-down research training from U.S. and other institutions
- determine sorghums place in local environment, i.e. relationship with disease and pest organisms.	- use survey information to expand awareness of scientist at all levels		

Principle B: Linkages

What needs to be done	How to do it	Who should do it	What limits it
- Develop linkages from farmer to research, farmer to extension and research to extension	- Develop integrated projects which encompass all parts of the system.	- National research centers - Ministry of Ag officials - Donor agencies and employees	- Willingness on part of donor and government agencies to involve themselves in direct contacts farmers.
- Link donors together so projects are coordinated	- Provide incentive for research and ext. agents to become involved in on-farm problems		- Belief on part of institutions that all knowledge should pass down
- Link donors with research and farmers	- Encourage donor agency personnel to go to the field		- Institutional infighting to secure "best" projects

Principle C: Risk Minimization

What needs to be done	How to do it	Who should do it	What limits it
- Develop varieties of sorghum which increase yields while maintaining yield stability	- Use local landrace varieties as the basis for building improved varieties	- National res. centers - CRSP - IARCs	- Technology is more advanced in high input-high output ag. - "Green revolution" psychology among research and donor community - Limited available germplasm with desirable traits
- Develop synthetics or mixes which respond to the environment in similar fashion to local farmer plant mixes	- Improve yields without affecting food quality or other important physical characteristics of the		
- Breed for increased efficiency of water and mineral utilization	- Use genetic sterility to build populations which include both local and exotic material		

Principle D: Local Resources

What needs to be done	How to do it	Who should do it	What limits it
- Collect and catalog local landraces and varieties of sorghum	- Establish and/or improve national germplasm banks - Provide training for collectors, enumerators	- Nat. Res Centers - IARCs - CRSP - Other donors	- Lack of funding - Loss of local germplasm due to changing farming patterns
- Catalog local cultivation, harvest, storage and food preparation technologies	- Survey selected systems for major differences in the way parts of the system are integrated	- Local Universities - Extension service	
- Determine how farmers select and maintain local varieties			
	- Emphasize food preparation and quality in antho/social studies	-Univ, CRSP, Extension	- Lack of recognition of the importance in quality factors

Principle E: Heterogeneity

What needs to be done	How to do it	Who should it	What limits it
- Determine differences in plant type and food quality and preparation across geographic and cultural boundries.	- Use local knowledge and surveys to accumulate data	- Research/Exten personnel - Donors, CRSP, IARCs	- Lack of funds - Lack of felt need - Lack of knowledge about varying needs among groups
- Breed for varieties which fit the broad differences found. Minute differences will have to be dealt with by local adaptation by farmers	- Create populations and synthetics which contain local genotypes, one for each area or grouping - Cross exotics with appro. qualities to locals in pedigree breeding system	- National Res. Centers - CRSP, IARCs	- Number of different varieties is restricted by funding - In general, 2-5 types should suffice for most countries

Principle E: Role of Women

What needs to be done	How to do it	Who should do it	What limits it
- Direct additional extension and research work to women, especially those who are making on-farm decisions	- Encourage national policy to reflect the fact that many if not most of the decision makers are women	- Donors - National institutions of research and extension - CRSP, IARC	- Active discrimination against girls in primary/sec school - Few women chosing ag as career - Women serve dual roles, not as easy to remove for training
- Increase the number of women in research and ext.	- Push for training of women in Agriculture		
- Move women into farmer training situations		- Ministries of Ag, Ed	
- Determine role differences	- conduct surveys/studies		

Principle G: Management for Sustainability

What needs to be done	How to do it	Who should do it	What limits it
- Determine maximum sustainable yields for cultivar/ environments	- Extensive on-farm trials over time	- Ag research and extension - Universities	- Difficulty in studying dynamic systems
- Determine sorghums role in total ag system, and use that information in producing new varieties	- Economic and social surveys	- Universities	- Role of component parts of system change with time and space

Principle H: Local participation

What needs to be done	How to do it	Who should do it	What limits it
- Establish direct links between research and farmer	- Make on-farm visits and trials more frequent and viable	- Research/Extension	- Lack of funds
- Get farmers involved in the actual science through "farmer selection blocks" or other means	- Determine who (men or women) makes seed selection and involve them in selection of prefered types from local/exotic populations	- Nat research centers CRSP, IARC	- Lack of working knowledge of a) how farmers select b) how to incorporate this input into a breeding program
- Access local expertise to determine food quality	- Use local farm women to conduct food quality trials for local sorghum dishes	- Res centers - Universities, CRSP, IARC	- lack of appreciation of the importance of food quality and consumer acceptance in sorghum breeding programs
- Involve local farmers, ext. agents, scientists in project planning and evaluation		- Donors, Res. Centers, CRSP, IARCs	- Top-down mentality - Difficulty in bridging gaps between farmers in Magarini and donor agents in Nairobi

10. Efforts of improve sorghums have been on-going in Sub-Saharan Africa for more that 40 years, but the rates of adoption of the improved varieties have been minimal. Politics have to accept much of the blame for this lack of success in Africa, because in India and Mexico similar efforts have been extremely successful. Part of the problem, however, certainly does lie with the underlying assumptions used by breeders in Africa, and their response to a very harsh, undependable environment. It would seem that fundamental mistakes were initially made in assuming that western technology in the form of semi-dwarf, high-yielding cultivars, even if adapted, would fit into the African farming system. Some of these varieties are being grown, but generally for cash sale and not for home consumption. To move beyond this point, it appears necessary to start with sorghums currently grown by farmers, and move yields upwards without disrupting the basic adaptive features of the local variety. For example, farmers fields are often mixtures of several distinct sorghum types, each having specific quality features, disease/insect resistance and agronomic characteristics. Exact matching of that mix will be difficult, but the principles involved will need to be followed. Pure lines will not likely have adequate pest resistance, and unless the grain quality of the new variety comes close to matching that of the local, it will not likely be adopted. Grain color, product palatability, storage quality, and marketability will also be important.

11. To actually arrive at the point where sorghum breeders can produce such an acceptable variety, close attention will have to

be given to all of the Principles and Concepts, especially A) Systems Approach, to account for all of the social and economic forces involved in decision making; C) Risk Minimization, producing a variety with acceptable stability that will not endanger the farm family in difficult times; D) Local Resources, in that local varieties, cultivation and food preparation techniques must all be used; E) Role of Women, as women are generally both farmers and cooks, and make many if not all of the decisions relating to the final acceptability of the variety; and H) Local participation, because none of the necessary information can be garnered from any other source, and no one can determine the final acceptability of the technology.

12. One of the problems facing African agriculture is that while men receive the benefits of research and extension expenditures, women are often the real farmers, and all too often they do not get access to new information and technology. Men sat around discussing new technology while their wives implement the old methods out in the field. In addition, and of equal importance, is the fact that women control the end product, from grain to ugali, uji, kiara or fermented beverage. Without their advice and consent, no effective change in technology is possible. There is an urgent need for women in research and extension. There are often cultural barriers exist which prevent male agents from working with the female clientele. In addition, it will be difficult to collect the information from farmer/consumers needed to advance sorghum breeding technology if trained women are not available for the survey and interpretation work.

13. As noted earlier, the reasons for past failures and hopes for future successes in sorghum breeding efforts in Sub-Sahareqn Africa lie in the use of local resources for germplasm, expertise, guidance and verification. If breeding efforts use local cultivars as the foundation of the breeding effort, try to emulate local variety mixes, match local quality parameters and use local people to test the final technology, success is far more likely then past experience has provided.

POLICY ISSUES

14. There are several issues which appear to be U.S. policy that act as constraints to the development of sorghum in Africa. Of greatest importance is the policy within USAID which limits projects to the short-term, 3-5 years as a rule. The simple fact is, that the kind of work necessary to develop sorghums to assist low-resource agriculturists will take 10-20 years, and when these efforts are fragmented as they have been, each new project starts at ground zero, gets 1/3 or less of the work done, and is terminated. A few years later the whole thing starts over again, and no one is better off. A second issue is that USAID, as it currently works, cannot attract and keep the quality technical assistants necessery to complete these long-term projects. Even if projects are to be long-term, they are not better off if the personnel necessary to make them work are rotating in and out every two to four years. A third issue is the USAID propensity to spend vast sums of money quickly to initiate a project, then get out. The tendency is to spend $10M in 3 years, when the same

money spent over 20 years would accomplish far more lasting results. Another related issue has to do with food assistance in areas where sorghum is or should be the predominant cereal crop. Too many times farmers grow crops such as maize (corn) which has poor drought tolerence. When it fails in droughts, these same farmers are often supplied with U.S. yellow corn as relief food. This simply replaces the maize they should not have tried to grow in the first place, and further displaces more appropriate cereals such as sorghum or millets. A more appropriate policy would be to provide relief food which fits the environment into which it goes, so that people in those areas do not develop tastes for crops their environment cannot sustain.

15. African states also have policies which tend to retard progress in breeding sorghum for low-resource agriculture. In general incentive to produce food are insufficient, and markets are haphazard if present at all outside of the local area. Until these policies change, farmers will be reluctant to produce an excess above family needs, no matter how productive their new technology makes them.

16. An increased emphasis on plant breeding in general, and sorghum breeding specifically has the potential to dramatically change the status of low resource agriculturists if the policy of the donor states clearly that it must be done in the context of the user group. There are places in Sub-Saharan Africa where sorghum hybrids are the most logical crop, and breeding efforts should be directed to match. For most of the region, however, the breeding efforts will have to be very much different, and policy should be clear on that point. It is most important that

USAID not restrict their assistance to only one "type" of breeding work, however, as in most countries there will be client groups which need sorghums from all levels of existing technology, from farmer selected populations to U.S. type hybrids.

17. The reforms in U.S. development policy necessary to develop the kind of successful low-resource agriculture based on sorghum (where appropriate) have been touched on, and are all related. In the broadest sense, a change in committment is required. USAID must recognize that all agricultural research is long-term in nature, and must reflect this in development projects. For breeding programs in particular, the very first results will not show for 7-10 years, and 15-20 years may be required to establish a program which will continue after technical assistance is withdrawn. To implement such projects, however, is presently impossible because the system of contracting for individual projects prevents the "accumulation" of scientists committed to international development. Because universities cannot support international scientists between contracts, those who would choose to have such a career are unable to do so, and USAID ends up staffing too many projects with people who come and go without ever becoming effective. If USAID would establish permanent ties with universities (perhaps following the CRSP model), they could recruit and hold international experts, and USAID would have a pool of effective scientists who were both committed and current in their discipline. Together with these two policy changes should come one of committing funds in smaller quantities over the longer terms discussed above. One million dollars will buy a

ton of equiptment for an experiment station, most of which will be derilict in 3 years, or it could keep that same station running for 10 years or more. Once a project has sorghum research underway, it should sustain it for the long term, so that the local scientists who take over control of the project are not stymied by a lack of local funds, as nearly always happens now.

18. The primary problems in education and training are closely related to the life of project problem just discussed. We have trained many sorghum breeders, agronomists, entomologists, etc, for Africa, but few of them are effective at present. One problem is obviously money, but of greater concern is that most do not have the experience to do good science upon their return. In the U.S. we hope that each generation of scientists will build on the accomplishments of their predecessors. In Africa, the men and women we train seldom have the chance to ever work with more senior scientists, and because of their spacial and temporal seperation from each other, each rebuilds the same road long abandoned by the last to occupy their position. If we trained in conjunction with long-term projects and long-term technical assistance, we could develop that first generation of local senior scientists, train the second generation, and let them build upon the first, thus starting that chain reaction which has to date been conspicuous by its absense in most African nation's research programs. If training is being done at institutions within an organization like INTSORMIL where long-term committments to development are in place, both the money and experience issues could be ameliorated by providing the Professor with adequate money for travel on a yearly basis for a few years,

and a "start-up" fund for the student, so that upon his/her arrival back home they had resources to begin working. A few thousand dollars a year could make the difference in success and failure to a young scientist in Africa.

19. Sorghum research remains an urgent priority in Africa. There has been increased awareness and interest in sorghum since the drought at the beginning of this decade, on the part of donors as well as national governments. ICRISAT, INTSORMIL (Sorghum and millet CRSP), USAID bilateral projects, as well as projects from other countries are all placing increased emphasis on Africa. ICRISAT's involvement, in view of their mandate and maturity, has been less than hoped for in terms of promoting food self-sufficiency. Their current emphasis on high technology and on regional programs does not appear at present to be effective. This may change with time. While the sorghum and millet CRSP INTSORMIL is only in its 7th year, its influence in Africa is already quite strong, and with very little financial support compared with ICRISAT, for example, has assisted countries all over the continent with equipment, supplies and technical assistance. More importantly, these relationships are scientist to scientist, and long-term in nature. Given all of this, it still remains that sorghum research in Africa is still in its infancy, and all of the work all of these institutions can do will still not be enough until Africa becomes food self-sufficient.

20. Potential of Sorghum Breeding to enhance low-resource agriculture in Sub-Saharan Africa.

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"The genetic code carried in the seed is especially valuable to the farmer with limited resources" (Francis, 1986)

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If the kinds of policy changes outlined above were to be instituted, sorghum and low-resource farmers in Sub-Saharan Africa would both face a much brighter future. Where today small farmers produce 500-750kg/ha of sorghum, a sustained program of assistance should be able to double that in 10-15 years just by changing the genetic component of the system (i.e. the seed). It would be expected that incremental yield increases in some cases would result in increased inputs or improved management, and this could well result in a second doubling in many areas of the continent. This kind of change will not be evenly spread throughout the continent, however. The acid soils of Mali and Niger are simply not as productive as the vertisols of Sudan or the Alphisols of East Africa, and the rate and quantity of change will not be as great there. While mean yields in these two areas are now roughly the same, potentials in some parts of West Africa may only be 12-1500kg/ha, while they may reach 3-4000kg/ha in East Africa (all under low-resource/high-management systems). Assuming farm sizes do not continue to decrease sharply in the low-potential areas of Africa, these yield levels should provide family food security and an excess for sale as a cash crop.

21. In the type of breeding approach already defined in this document, it should be possible to start moving varieties out to

the farmer after 5-8 seasons (2 1/2 to 4 years where 2 seasons per year can be obtained). Because of the attempt to emulate farmer varieties, genetic purity is not necessary, and is probably detrimental. If these new "varieties" are indeed higher yielding then the locals, and if they prove stable over seasons, and if they meet or exceed requirments for food quality and grain storage, then adoption will happen rather rapidly. Building on the initial experience of the farmers, the breeder can then continue to refine and purify the component parts of what should end up to be a synthetic variety or composite variety. This will offer the farmer hybrid vigor without the burden of purchasing new seed each year. The breeding effort to produce these synthetics will probably take 10-12 seasons, and testing another 2-4 seasons before they are ready for wide scale distribution. It should be stressed, however, that with continued farmer involvement in the process, the valuable parts of the synthetic (to the farmer) will continue to flow from the breeding program into farmer's fields, and their results fed back into the breeding project. Once the technology is farmer-tested and approved, adoption rates will match those seen in the U.S. for hybrid sorghum or in Kenya for hybrid maize. In 10 to 15 years 90% adoption should be expected. It then becomes a continuous chain of mutual feedback from the farmer to the sorghum breeders and agronomists and back to the farmer, with the system being made more effective at each exchange.

22. To be successful, new sorghum varieties must fit into the existing farming system. They will not be adopted otherwise. Once they are into the system, and increasing net production and

income, they will stimulate changes. If a farmer's yields are increased 20% by the first generation of new varieties, and she/he invests some of that increased profit in organic manure, then the system capacity will increase. At some point, they will have a system where the sorghum variety is once again limiting, and the next generation of more productive varieties should be available. In other words, this technology should not demand changes in other components of the low-resource system, but rather stimulate such changes.

23. There are two areas of research currently on-going in the U.S. and Africa which are of critical importance to this discussion. The first, and most important, has to do with food quality. This appears to be the single most important factor in farmer acceptance of a new variety even if they are satisfied with its yield and stability. In addition, the qualities desired vary greatly across tribal and ethnic boundries. The first issue is to define these quality parameters, determine their genetic factors, then breeding work can start. The processing and cooking techniques of these farmer/consumers are also in the equation, and not enough is known about these factors. This is the primary reason why it is so important to start with what is known to be acceptable, i.e. the traditional variety.

24. A second technology of importance, and about which little is know, is the production of synthetic varieties in sorghum. These lines have hybrid vigor, but replacement of seed every year is not necessary. Work is currently underway to define the optimum number of lines to include, how long the hybrid vigor

will last, and if a technology can be developed whereby the plant breeder will basically produce the synthetic, and the farmer will select and maintain his own variety with specific adaptation to his own farming situation. This latter research will have to be done in Africa, and is years from completion.

25. Biotechnology shows distant promise in providing new adaptive features for sorghum and other crops which would be useful in low-resource agriculture. In the short and medium term, however, talking about the needs of low-resource agriculturists and biotechnology is equivalent to talking about problems light-years apart in scientific terms. If, for example, gene transplant technology some day provides sorghum with a system of genes to fix nitrogen, then of course that would have tremendous impact on Africa, but not until those characteristics are transferred into acceptable varieties by traditional plant breeding techniques. USAID should not even consider funding this type of basic research, when the problems in low-resource agriculture remain how to apply the technology of 20-50 years ago to a different system. Biotechnology will be funded by many other sources, but few are interested in funding the kind of developmental technology which will provide the African farmer with the ability to feed his family every year, and help develop his country by providing excesses to the marketplace.

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Revisions from J. Mann   Appendix I

As previous discussions have indicated, there is very little documentation coming from National research programs in Africa. In those areas where I am familiar (East Africa), there are no reports available for ther last 9-12 years. The comments in question are from two sources; one, comments of colleagues within INTSORMIL and ICRISAT, as well as country reports which appear in the proceedings of the East African Regional Sorghum and Millet Workshops 1-4, ICRISAT/SAFGRAD, Nairobi. A second source is personal experience, which may or may not be valid. I don't think there is much question about current production levels. These are available from FAO production reports, and some donor/local government studies for individual countries. Because almost no work has been done in breeding for low-input agriculture, most of these numbers have come from personal experience. In Tanzania, we produced in excess of 5T/ha with inputs of 20K/ha on Nitrogen, and no other inputs at the Ilonga station. In sandy soils with no fertilizer and no other inputs, we obtained yields of 3.5 T/ha. It must be remembered, and it is so stated in the paper (para 20), that West Africa is verymuch different in terms of potential. A second factor, which in in the paper, but not noticed by at least one reviewer, is that what is being described is the potential under low inputs, not low management. I hope this point is clear, that a number of practices such as intercropping, use of FYM where available on-farm, etc will be necessary to reach the production figures of 2-4T/ha. I still believe, however, that major yield increases of 50-100% can be obtained in areas of Africa with reasonable soil conditions with just the use of improved seeds.

Paragraph 4

I'm not sure it is possible to quantify the rates of adoption of improved sorghum cultivars. The figure of 5-10% is just a best guess estimate of a number of my colleagues, including John Axtell, John Schuering, Dave Andrews, Chuck Francis, Fred Miller and Darryl Rosenow. In my travels throughout East Africa, inlcuding Kenya, Tanzania, and Uganda, it is rare to see improved cultivars, and these are areas where improved cultivars will grow and increase yields. In East Africa it is primarily poor fit to the farming system (food quality, maturation period, etc) which has prevented adoption. In West Africa, it appears to be more a problem of poor fit to environment which has prevented the spread of improved cultivars. I was interested in one reviewers comments about the use of local cultivars as the foundation of a breeding program. He named Serena and Serado as examples of successes in the use of exotic germplasm. I think with 10% adoption rates after 25 years (in the case of Serena) this is a classic failure. Even Hageen Durra I has suffered a serious setback now that food is plentiful in (at least Northern) Sudan, apparently becuase it does not make good Kisra, the endosperm being too corneous. There is already a shift in production back to local federita and hegari types with acceptable food quality.
An additional factor seems to be that the moneylenders/seed suppliers do not like the hybrid becuase the increased yield levels threaten their hold on the farmers. That is, if the farmers produce too much sorghum, they might be able to buy themselves out of hock!

The "sorghum belt" as referred to by Earl Leng in the quote corresponds more or less to the ecogeographic belts most ofter termed the Sudanic and Sahelian belts, which stretch across Africa from the Sudan to the West Coast, and includes most of Sudan, Chad, CAR, Northern Camaroon and Nigeria, Niger, Burkina Faso, Mali and Mauritania. This would be something like 7-15 degrees north Latitude.

Paragraph 5 (rewrite)

The status of sorghum breeding programs within the major development sassistance organizations has taken a significant jump since the African drought of 1981-85. It has become evident to many that drought tolerant cxrops such as sorghum must have increased emphaisis if Africa is to become food self sufficient. The 7 person, $18M first phase of the ICRISAT/INTSORMIL sorghum and millet project in Zimbabwe is now about 2 years old. SIDA (Sweden) has a sorghum breeder in Zambia, an INTSORMIL breeder was posted to Tanzania in 1984 for a short term assignment, and USAID is now within 4 months of posting a sorghum breeder to Kenya within a 10 year, $40M ag research project. USAID and World Bank both have money allocated for sorghum work in Sudan (about $40M total for extensive research/training/extension projects with sorghum as a main component), and USAID is supporting to some extent sorghum work in Egypt. In West Africa USAID is currently supporting Ag research in Niger and Mali, both countries receiving sorghum breeding assistance. The Niger project is currently up for renewal for another 5 years, and the Mali USAID/ICRISAT program is due to continue indefinitely. There is evidence that ICRISAT will soon start a West African sorghum center in Nigeria on the scale of the Sahelian Center (millet) and the effort in Zimbabwe. Other projects of which the authors are unaware are undoubtedly underway as well. INTSORMIL, funded by USAID's Science and Technology division, spends a total of perhaps $1.5M a year in Africa and Latin America, on on reseach related to problems in those areas. In Africa, collaborative efforts exist in Senegal, Mali, Niger, Burkina Faso, Sudan, Kenya, Uganda, Tanzania, Zanbia, Zimbabwe and Botswana. Even so, the evidence to date is that sorghum breeding research in Africa continues to be underfunded given its strategic importance in those dryer areas of the continent. Sorghum breeding alone should be funded, by local and donor efforts, at the rate of $.5M to $1M per year in each of the 30-35 countries in Africa where sorghum is or should be a priority crop.

Paragraph 6

This statment assumes that increased production levels imply some additional risk. For example, the purchase of imputs increases financial risk, and crop failures become economic as well as food sufficiency problems. In areas where land is adjuticated, farmers often have to borrow against the title of their land to purchase inputs. Crop failure means not only the loss of food, but the means of production as well. The implication of the paragraph is, then, that by moving in incremental steps up from the farmer level, income can initially be boosted without substantial risk increases. At a certain point, where for example inputs can be purchased from cash reserves (actual cash or cattle, goats etc), then increased risks can be taken by the farmer in terms of cash inputs to his/her farming system.

Paragraph 7

Perhaps a better bullet would be " Poor utilization of the germplasm base". The intent is to say that most national and IARC breeding programs do not utilize more that a tiny fraction of the germplasm available. The germplasm base in sorghum is very large, that portion which is utilized is very small.

Paragraph 19

ICRISAT began operations in about 1973-74, with a mandate to improve sorghum production in the semi-arid tropics. I do not know their budget for sorghum, nor do I know the number of scientists they employ, but they spend many millions each year, and employ hundredes of scientists at "local" and "expert" levels in India and around the world. To my knowledge, the only ICRISAT released sorghum line or hybrid outside of India is Hageen Durra I, and while I do not belittle that achievement, both of the lines which make up that hybrid were established lines combined and tested in Sudan by Gabisa Ejeta, an ICRISAT employee, with considerable imput from Darrly Rosenow, Texas A&M sorghum breeder. Dr. John Scheuring did an excellent job in Mali, but while he was paid from ICRISAT, the money was from a direct bilateral project between USAID and Mali. My greatest concern with ICRISAT is their new emphasis on biotechnology. They have spent millions of dollars in the last 1-2 years on laboratories and equipment for doing tissue culture and genetic recombination work, in my mind at least a task far removed from their mandate to improve sorghum production in the semi-arid tropics. The arguement that they rely on biotechnology only to aid this effort is misleading for two reasons. First, there is no evidence of any payoff from this new technology in the 5-10 year horizon, and secondly, the work is being done in the U.S. by other organizations better prepared to do the work and with such a mandate. There is plenty of applied work to do in the developing world with existing technology and available germplasm.

Paragraph 22

A classic example of this would be the development of acid-soil tolerant sorghums. In areas with soil pH's of 4.5 to 5, sorghum yields are often extremely low unless large amounts of calcium and other minerals are added to the soil. Acid-tolerant sorghums have increased yields from almost nil to 1-1.5 T/ha. This increase allows farmers to buy some soil amendments the next season, and at very high benefit:cost ratios, this allows higher profit margins and higher input levels. At some point, when the farmer has changed the growing environment sufficiently, the sorghum which are very acid-tolerant are now longer the most productive, and a higher yielding, but less acid-tolerant sorghum can be grown.

General revision requests

I do not have any specific data on funding and resources currently being made available to IARCs, national programs etc for sorghum work, other than that already given. I would comment on the regional approach as compared to a more mnational approach, however. From what I have heard and seen of IARC regional centers, there appears to develop in these institutions a more basic, less applied mentality. There is often a considerable amount of good short term training done at these institutions, but very often they are lacking in innovative and creative areas. Too often a strong central figure dominates the thinking, and soon everyone thinks alike. This results in scientific stagnation, and reduces the outreach efforts. This was the case at CIMMYT in the last decade, and I am told is the case at IITA and the ICRISAT Sahelian center currently. It appears to be a mistake to cloister too many people in these centers, at least with their having strong motivation to move out of the confines of the institute. While bilateral projects are rife with problems, at least they do not tend to become stagnent. Too often regional activities are too superficial. There is also a tendency to bring cooperators from other countries in frequently, often just when those scientists need to be home doing their own work. In general the science at IARCs is good, but often not very useful to the average farmer in the LDCs.

In spite of what I have said about sorghum breeding being underfunded, and its ability to make changes without other changes in the system, I would have to say that agronomic research is the most underfunded area in sorghum research in Africa today. Considerable resources have gone into sorghum breeding, but the results are not too useful. Care needs to be taken that the same thing does not happen in agronomic research. In the breeding area, more work needs to be done on real breeding, and less on the evaluation of exotic germplasm year after year. Seed multiplication does need increased emphasis in most countries in SSA, with Sudan and Zimbabwe possible exceptions. Experience has shown that private entities are most suitable for this, as government efforts have failed consistantly, at least in East Africa.

The balance of resource to needs in many SSA countries is based too many times on a haphazard pattern of appropriations in the past rather that currently assessed needs. Export crops often have received heavy emphasis to the detriment of food crops, and within food crops emphasis more often reflects the bias of the decision makers that the countries needs. As a rule, those in positions of authority tend to come from higher potential areas of the country due in part ~~to~~ education patterns in the past (i.e. many of the early schools were placed where expatriate missionaries and teachers were willing to live). In Kenya, for example, most people in the Ministry of Ag come from the Western or Central or Western highlands. In Tanzania, they come from around Mt. Kilimanjaro or from the highlands west of Lake Victoria. This naturally has resulted in a bias towards the crops prominent in those regions, often to the detriment of such crops as sorghum and millet.

Recent assessments of return on investments for ag research done by the Kenya USAID mission show for maize an expected return of about 15% per year on investment. For sorghum research, I estimated that a 50% increase in yields could be obtained for 30% of the hectarage in 15 years, paying for an initial investment of $2M in just over 7 years. In general, ag research is thought to pay off in the general area of 10-35% per year.

FINAL DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

OTA Technical Paper Series: Root Crop Breeding

by

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FINAL DRAFT

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OTA TECHNOLOGY PAPER SERIES: ROOT CROP BREEDING

Introduction

Cassava, yams, sweet potatoes and aroids are major sources of food energy for millions of limited resource agriculturalists (LRA's) in Sub-saharan Africa (FAO 1986, IITA, 1985a, 1986, Hahn 1984). The leaves of cassava, sweet potatoes and cocoyams also provide a valuable source of protein and vitamin (FAO 1986). Addition [Cassava and sweet potatoes are also potential feed sources for animals. Until recently, root crops have been relatively neglected by most policy makers and institutions. This is in part because of the frequent absence of a coherent policy framework for the traditional food sector, particularly for the root and tuber crops and a lack of coordination of efforts to develop these crops (FAO 1986, Horton _et_ _al_. 1983). Cassava, sweet potato and the aroids can grow under poor land conditions, and can be intercropped with other food crops such as cereal and legumes and cash crops, such as cocoa and coconut (Hahn 1984). If high yielding disease and pest resistant varieties are developed and disseminated to LRA's and improved storage and processing technologies and marketing strategies are developed, production of root crops could be expanded substantially to provide a low cost highly nutritious food source. This could be achieved by root crop breeding programs involving conventional and biotechnological approaches in close connection with farming systems and food technology programs focused on root crops. Since these root crops do not directly compete with exports of U. S. agricultural commodities, developmental assistance to increase their production would enhance food stability for LRA's without causing negative impacts on U. S. agricultural exports.

Root Crop Breeding

Root (and tuber) crop breeding programs are geared towards improving cultivars of these crops to obtain high stable yields, resistance to major diseases and pests and a quality product acceptable to African consumers (Hahn 1984). Root crop breeding in Sub-Saharan Africa should not only be limited to increasing yields for human consumption but also for production of feed for animal production. These objectives can be achieved through an interdisciplinary team approach involving agricultural, biological and socio-economic disciplines (IITA 1985). Breeding priorities differ by crop use and region. Production of root crops for subsistence for animal feed or for industrial production will have completely different cultivar requirements. Also regional difference in diseases and pests indicate different breeding priorities. Specific techniques are required for breeding each root crop but, in general, root crop breeding involves identification of sources of the specific characters of importance through screening and selection of wild and cultivated species collected from different ecological zones. Propagating materials are usually collected either as seeds or plants in tissue culture to minimise risk of disease introduction. This is then followed by hybridzation to incorporate these characters into more acceptable cultivars. Both interspecific and intraspecific crosses (crosses between cultivars and closely related species) should be made to obtain breeding populations. Continuous cyclic evaluation, selection and recombinations using various breeding schemes including a half-sib family selection scheme, recurrent selection, full-sib family selection and back crossing should be used to improve breeding populations. These schemes allow for incorporation of many different genetic sources from many countries and institutions in Africa (Hahn *et al*. 1983,

Addition

Addition

codification

Alvarez and Hahn 1983, Hahn 1984). Performance tests, disease resistance and farmer and consumer acceptability should be done in all the ecological zones in cooperation with local institutions as well as on the farmers' farms. Once clones have been stabilized and tested over a wide range of conditions, they are multiplied and distributed to areas where they were found to be most productive. Crop uniformity can be achieved since these crops are usually propagated Addition asexually. Easy and rapid dissemination of disease free propagating materials can also be achieved through tissue culture. Particular attention should be given to testing improved varieties in cropping systems used by LRA's.

Cassava (Manioc esculentum)

Cassava is the most widely grown of the root crops, being adaptable to a wide range of agro-climatic and soil conditions. The major biological constraints to stable production of cassava in Africa are diseases such as cassava mosaic and bacterial blight diseases and insect pests such as cassava mealy bug and green spider mite. Cassava varieties also have a high cyanide content in leaves and roots and are susceptible to nematode damage (Haha 1984, 1985). Breeding programs must therefore address solutions to these constraints. The techniques used for cassava breeding are those described in the section of this paper on root crop breeding. Techniques developed for breeding for disease and insect control are already being used in countries such as Guinea, Bissau, Camerrons, Ivory Coast, Ghana, Nigeria, Rwanda, Zaire, Zambia and Malawi.

Yam (Dioscorea spp).

edited Countries in the "yam zone" - Nigeria, Benin, Togo, Cameroons, Ghana and the Ivory Coast produce 90% of the world's yams (Coursey 1983). The most critical problems in yam production are those concerned with the ecomomics of production. Yam requires high labor input, it has low yield per unit input, requires extensive preservation and bulky propagation materials. Unlike cassava, sweet potato and aroids, yam does not perform well on marginal lands. Yam, as with all other African food crops grown by small scale farmers, are generally intercropped. It requires very fertile soil and therefore cannot be grown successfully on short rotations without fertilizer inputs. Despite the high unit cost to produce yam, in the "yam zone" it is a preferred food, a high valued cash crop and an important source of income for LRA's. For this reason, yam breeding programs should not be abandoned but should be encouraged. Yams would not be considered a potential feed source for animals. Yams are ancient crops and have acquired a heavy burden of religious and magical significance that hardly applies to any of the other tropical crops (Coursey 1983). In developing varieties for low resorce agriculturalists, yam breeding programs should aim at the development of clones that are resistant to nematodes, major insects and diseases and produce high yields under minimum inputs. They must also have high adaptability to the various local farming systems including their agronomic practices. The program must also aim at developing plant types which require no staking, improving the tuber shapes into those that are easy to harvest and handle, stable yield and improved storability. Well shaped tubers will not only be easy to handle but will reduce waste during preparation for cooking. Such breeding programs will consequently reduce most of the constraints of high economic inputs in yam production. For sccessful hybridization, male and female plants should be stagger planted to ensure flower synchronization since yams are normally dioecious (Alvarez and Hahn 1983). Application of hormones to induce flowering and ensure flower synchronization could be evaluated. This system would allow the breeding program to provide

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genetically diverse material with a high frequency of desirable genes which can be easily exploited by low resource agriculturalists.

In order to combat the constraints of the high volume of planting material, technology using presprouted minisetts and plastic mulch has been developed to produce large numbers of seed yam. This method has resulted in a 30% increase in seed yam over conventional production system and has substantially reduced the cost of seed yam production (IITA 1985). The minisett technology also makes possible the direct marketing of seed size yams for consumption, thus removing the need for staking, mound building and dealing with bulky propagation materials.

Sweet Potato (Ipomoea batatas).

Sweet potatoes are grown throughout all the regions of Sub-Saharan Africa, but in only a few countries - Burundi, Rwanda and Uganda - is this crop a major staple. Although it is possible to grow sweet potato under a variety of agro-climatic conditions, and its yield potential is very high, it is not a food that is widely accepted by consumers as a staple food. This is mainly due to its sweetness (FAO 1986). Generally, the production of sweet potatoes in Sub-Saharan Africa is characterized by small landholder subsistence farming, poor agronomic practices, unavailability of improved cultivars, prevalence of diseases, nematodes and weevils. Breeding programs should therefore aim at achieving high yields with low inputs and development of varieties resistant to weevils, nematodes and viruses, with long shelf-life and consumer acceptability (Hahn et al. 1983, Hahn 1984). After high yield and weevil resistance, a major focus of sweet potato breeding programs in Africa should be on quality (taste, texture and nutritional value) and acceptability by consumers (Martin and Jones 1986).

Addition

Due to the physiological system of incompatibility and sterility in sweet potatoes, polycross nurseries consisting of several selected parents based on their progeny performance and compatability groups should be set up with several plants per parent and with several replications to provide an equal chance of crossing (Jones 1983, Martin 1983, Hahn *et al*. 1983). This technique together with those described under root crop breeding would permit the participation of different national programs in the provision of genetically variable materials for testing under local conditions. It could also result in the development of clones to be tested without fertilization at several locations and would also result in the distribution of disease free planting stock of several clones.

Aroids (*Xanthosoma* spp. and *Colocasia* spp.)

The production of cocoyams require an ample water supply and thus tend to be concentrated in areas of high rainfall. The two main types of cocoyams are taro and tannia. Cocoyams are important in four of the humid countries of Sub-Saharan Arica - Cameroons, Ghana, Gabon and Nigeria (FAO 1986). Until quite recently when technology was developed for flower induction, improvement by breeding was not practical. Flower induction can now be obtained by the use of gibberellic acid (Alamu 1983) which can be pollinated for hybridization and tested for specific characters. In order to introduce variability, germplasm should be evaluated and screened together with the local collections for disease resistance, improved storageability, high yields and improved morphological traits. Through the collaborative work with the Cameroon National Programs and IITA, germplasm banks are being established and clones and varieties as well as wild species are being collected to increase the genetic base (IITA 1985a, 1986).

Status of Root Crop Breeding in Sub-Saharan Africa

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IITA and various national crop improvement programs in a number of African countries have made significant progress in the last decade in the development of improved cassava, sweet potato, yam and cocoyam varieties. Limited progress has been made in the dissemination of improved cassava varieties that are high-yielding, resistant to disease and insect pests, good in quality for consumer acceptance and low in cyanide content that are being grown in different ecological zones in Sub-Saharan Africa (IITA 1985a, 1986). Control of cassava mealy bug populations has been successfully implemented in countries such as Nigeria, Benin, Togo, Zaire, Congo and Ghana. In Nigeria, through the National Crop Research Institute and other state and local food improvement organizations, more than 80,000 hectares of farmers' fields are planted to improved cassava varieties. In Oyo state about 20% of the total cassava acreage was planted to the improved varieties. In other countries such as Sierra Leone, Zaire, Gabon, Tanzania, Sychelles, Rwanda, Liberia and Cameroon, farmer acceptance has been very favorable and more hectares are being planted to improved cassava varieties through the help of local and national programs and other national organizations such as USAID, FAO and IDRC (IITA 1985a, 1986).

High yielding weevil, disease and nematode resistant sweet potato varieties (sweet and non sweet) have been developed and are being tested and grown in most of the ecological zones. Although it is difficult to estimate the percentage of farmers using these varieties, reports from local institutions have indicated a large acceptance of these varieties by farmers (IITA 1985).

odified

The success story of farmers' adoption of the yam breeding program has been limited. This is because the program is relatively new and hybridization has been limited. New promosing clones of both white yam (*D. rotundata*) and water yam (D. alata) have however, been identified and are being produced by IITA for distribution to the National programs (Hahn 1983). One technology that has gained wide acceptance, especially in Nigeria, is the use of minisetts of yams and plastic mulch in the production of seed yam. This technology reduces labor costs and the amount of planting material per hectare (IITA 1985).

Several clones of cocoyam resistant to diseases have been identified and are being incorporated in the breeding program (Hahn 1983). Although farmer level tests have been done, no improved varieties are being used by the farmers.

The root crop breeding program has received great support from several development agencies both nationally and internationally. Propagation and Modified dissemination of improved varieties and technology are being carried out by the Root Crops Research Institute, National Seed Service, and the State Ministries of Agriculture in Nigeria, National Manioc Program in Zaire, The Rwanda National Root Crop Improvement Program in Rwanda and by the National Root Crop Improvement Program in the Cameroons (IITA 1985). Internationally, IITA has Modified played a major role in the development of the improved varieties of root and tuber crops which are multiplied and disseminated in other countries with the help of other agencies such USAID in Sierra Leone and Zaire, FAO in Gabon, IDRC and FAO in Tanzania, IDRC, USAID in Rwanda and Liberia and IDRC and AGCD in the Cameroons. ddition Although there has been progress in the development and acceptance of improved varieties of root crops, because of the importance of root crops in the African diet, and the potential uses of cassava and sweet potato for industrial, animal feed and other purposes and the percentage acreage planted to the improved varieties is very small, more emphasis must be put on local testing and dissemination of already improved materials to the farmer.

addition

Private seed farms must be encouraged to grow, maintain and help in the dissemination of these improved varieties for the different ecological zones.

There are several constraints in the development of roots and tuber crops apart from production constraints in Sub-Saharan Africa. These include both technical and socioeconomic constraints and those constraints that are related to marketing, storage and processing which together have significant consequences for prices paid by consumers and received by producers (FAO 1986).

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Specifically, some of the constraints are

- Land tenure system - LRA's may not have permanent transferrable title to land that they cultivate; thus there is little to invest in the land.
- Seasonality of production of the root crops creates sharp peaks in demand for labor.
- Lack of adequate and less expensive transformation methods and less sophisticated equipment that can be used by the illeterate farmer.
- Effect of prices on output is generally low since the bulk of root crops are produced for subsistence.
- Root and tuber crops are extremely perishable, require expensive storage systems, are very bulky and usually have to be transported over long distances.
- Absence of marketing organizations and therefore a wide disparity between producer and consumer prices.
- Because root crops are mainly for subsistence, there is inadequacy for research and extension programs.
- Lack of a coherent and integrated policy framework for these crops (FAO 1986, Christensen _et_ _al_. 1981, IITA 1984).

TABLE OF APPLICATION OF OTA'S PRINCIPLES AND CONCEPTS
ROOT CROP BREEDING

Principle A. Systems Approach

What needs to be done	How to do it	Who should do it	What limits it
Modified continue development of improved varieties of root crops and associated technologies based pupon prioritized needs defined by LAR's (limited resource agriculturists)	interdisciplinary studies of the overall environment including physical, biological and socioeconomic disciplines, input/output relations & the dynamics and constraints of production processing/storage and marketing. Focused efforts at the national level are needed.	national centers, universities, IITA and LRA's regional network	-inadequate & funding for long term systematic efforts

Principle B. Development Assistance

What needs to be done	How to do it	Who should do it	What limits it
improve linkages of root crops farmers with market economy	develop a national price support policy for root crops	national ments, LRA's	-inadequate government policy
	develop intergrated production, marketing and consumption policies for root crops	national governments, LRA's and universities	-inadequate government policy
	develop flexible credit systems for LRA's develop transportation systems (roads & vehicle transport) to move root crops rapidly from production areas to markets	national governments, banks, donors, national government with donor assistance	-inadequate government national policy -lack of understanding and innovative credit programs by national and international banks -inadequate funds -low priority interests by governments & donors

addition

transformation, processing and storage of these crops	develop cheap and less sophisticated implements that can be used to process these products in the remove villages	national centers	-inadequate funding - fundng should be directly given to the national governments not via a center like IITA

Principle C. Support Resourcefulness, Flexibility and Diverse Strategies

What needs to be done	How to do it	Who should do it	What limits it
encourage and improve root crop production by LRA's	develop high yielding, disease & insect resistant, acceptable root crop varieties that will grow well in the intercropping systems used by LRA's under local cultural and climatic conditions	national centers, IRAC's and universities	-inadequate government policy -low priority research emphasis by national governments -adequate funding
	develop improved methods of planting materials	national centers extension service	-low priority emphasis national government
	develop cost efficient methods for processing cassava at the village level	national centers IITA's & universities, private industry	-inadequate funding -low priority research emphasis

Principle D. Local Resources

What needs to be done	How to do it	Who should do it	What limits it
increase and preserve local root crop varieties and wild species	establish tissue culture banks	national centers universities, IITA	-lack of funds
	train more breeers and genetics and post at national centers & universities to work on root crops	national centers universities IITA	-inadequate national policy -lack of funds

Principle E. Heterogenecity of Agriculturists

What needs to be done	How to do it	Who should do it	What limits it
Monitor effects of new technologies and policies on root crop contribtion to food security & monetary income of LRA's	continuous survey and case study	anthropologists, economists, social scientists & agronomists working collectively (farming systems approach)	-lack of national policy -limited funding
change or adapt technologies or policies as demonstrated by the above surveys, case studies and new research	provide timely reports to designated government and donor agencies	farming systems teams via national centers IITA, universities	-limited funding
give high priority to innovations in credit & extension services for LRA's	develop flexible credit & training policies & strategies to assist LRA's	government, banks, donors, local communities involving LRA's	-low priority and and emaphsis by national government and donors

Principle F. African Women

What needs to be done	How to do it	Who should do it	What limits it
increased educational opportunities for women farmers	priority inclusion of women in training and extension courses	national centers, universities	-inadequate priority by institutions -traditions
	enrollment of more women in agricultural studies at the high technical high school and university levels	technical high schools,	-inadequate institutional incentives

			-special funding support for women -traditions
increased opportunities for credit, must be flexible because of land tenure system local traditions regarding the role of women	credit just for women LRA's	international banks, national governments	-lack of understanding and innovative credit programs by national and international banks -national land tensure systems
develop less labor intensive production and processing practices for cassava	prioritize research efforts in this area	national centers, universities, private companies	-personnel & funding in this area is limited -low priority for research development
minotor changes in policy and technology to ensure that women do not lose control of sources	continuous survey and care study	anthropologists, economists, social scientists, and agronomists working collectively (farming systems approach)	-inadequate national -limited funding

Principle G. Sustainability

What needs to be done	How to do it	Who should do it	What limits it
test the effect of improved root crop varieties in different agro-climatic regions for influence on soil fertility levels	long term research using improved varieties in cropping systems used by farmers	national centers	-limited funds
	evaluate soil resources using bench-mark criteria	national centers, IARC's universities	-limited funds
develop techniques for selection of root crop breeding lines & cultivars able to grow on low fertility soils with minimal depletion of soil nutrients	test multiple cropping systems with legumes and N_2-fixing trees that involve root crops	national centers OARC's universi-	-limited funds -limited fuhnds
	develop varieties capable of sustaining high populations of rhizosphere microbial populations that enhance soil fertility levels or nutrient uptake, e.g., mycor-rhizaor N_2-fixing bacterial associations	universities, IRAC's and national centers	-limited funds -low priority emphasis by governments and donors

Principle H. Local Participation

What needs to be done	How to do it	Who should do it	What limits it
involvement of LRA's in problem identification and research	in selected areas survey farmers for problems associated with root crops	extension personnel & farming systems teams associated with national centers, universities, IARC, LRA's	-limited funding and staff

How OTA's Principles and Concepts Can be Applied - Selected Examples

The resourcefulness, flexibility and diverse strategies of LRA's provide the mechanisms by which they survive on a day-to-day basis. Such mechanisms must be supported, encouraged and enhanced. Development and dissemination of high yielding, disease and insect resistant, nutritious, accdeptable varieties of cassava, yam, sweet potato or cocoyams that grow well in the cropping systems used by LRA's could increase crop yields and provide more food using the present cropping systems of LRA's. In order to establish the usefulness of improved varieties, it is important that mechanisms for distribution of improved materials to LRA's is increased. This requires continued and expanded dissemination of improved root crop varieties by LRA's from national centers and IITA via formal and informal (e.g. village leaders) extension services (Hahn andKeyser, 1985). Because of the wide adaptability and high potential yields of sweet potato, in addition to developing weevil-, nematode- and virus-resistant sweet potatoes, sweet potato breeding programs should focus efforts on developing low sugar varieties that are consumer acceptable and can serve as a stable food (Almazon 1986, IITA 1986, Martin 1983). The breeding program should also aim at developing varieties that can be used as animal feed.

addition

Cassava deteriorates within 2 to 5 days after harvesting, but can remain in the soil unharvested for 1 to 4 years. Because cassava is the most widely used root crop staple in Africa, there is a need to focus on developing high yielding, easily processed varieties and simultaneously develop more efficient, low cost, small-scale machinery for processing cassava for human and animal feed as well as industrial purposes at the village level (FAO 1986). In addition to freeing land used for cassava storage, mechanized small scale processing will relieve a lot of the drudgery of processing cassava for LRA's. Since nearly all

Modified

of the processing is carried out by women, such technology probably would relieve women from this task and provide time that can be used for education and training. As the process of mechanization occurs, the benefit in time saved and money earned should be predominantly channeled to enhance the quality of life of LRA's, especially women. The social/nutritional reports of small-scale processing must be carefully studied to ensure that money earned by women is not lost and the cyanide content is not increased (Wilson, Personal Communication). Such studies should be carried out in target areas by farming system teams, preferably of nationals (Lelel 1981), employed by national centers, ministries or universities.

As yield of root crops is increased, it is highly possible that soil nutrient levels may decrease, depending on many factors including cropping systems and fertilizer use. Cropping systems using improved and local varieties should be monitored for long term effects on soil fertility levels using "benchmark criteria" (Silva 1985, IBSNAT 1985). In addition to testing fertilizer effects on improved varieties in LRA cropping systems, research should be initiated to evaluate potentially beneficial plant microbial interactions that could biologically provide nutrients to plants, thus minimizing fertilizer requirements. Examples of such studies include legume-root crop intercropping systems, crop alley cropping systems, mycorrhizal effects on nutrient and water uptake by root crops, and beneficial associations of N_2-fixing and growth hormone producing bacteria in root crop rhizospheres (Hill *et al.* 1983, 1986; IITA 1984, 1985b; Kang *et al.* 1980; Mulongoy *et al.* ddition 19086). Use of animal waste in a mixed root crop animal production system can also be employed.

Based on experience of the last 15 years, these activities require a collective effort of national root crop centers, IITA, universities and extension agencies. The national centers have been given the responsibility by their government to increase root crop production and utilization. Successful results in Nigeria, Cameroons and Zaire indicate that increased technical support can result in significant development and dissemination of improved varieties and agronomic practices (see p. 21 for examples). IITA has established itself as an effective center of root crop research in Africa and in addition to developing improved root crop varieties, it trains hundreds of African root crop researchers and extension persons each year (IITA 1985), 1986; U.S. Congress 1984). Additionally, IITA has formal cooperative linkages with the other international agricultural reseach institutes working on root crops that are sponsored by the Consultative Group on International Agricultural Research (CGIRA). A number of universities in African countries have root crop research programs with many trained scientists. The root crop researchers at national centers, IITA and universities in Africa have developed an effective network of communication through the International Society of Tropical Root Crops - Africa Branch (ISTRC - AB), (Terry _et al_. 1980, 1983). The ISTRC - AB is made up of root crop researchers and extension personnel from 14 African countries representing African universities, national root crop research centers, IITA, extesion services and universities and international research centers outside of Africa. The ISTRC - AB leadership is composed of the leading root crop researchers in Africa and is funded by membership dues, grants by donor contribution (e.g. IDRC). The ISTRC - AB is an organization created in 1978 to stimulate research, production and utilization of root and tuber crops in Africa and the adjacent islands. It is the strongest and most active branch of the parent organization. ISTRC was founded in 1964 to support any type of policy leading to the general improvement of tropical root and tuber crop production and utilization. Exchange of improved germplasm, cultural practices, scientific expertise, equipment and published material among root crop workers throughout Africa is coordinated by both IITA and ISTRC - AB.

Policy Issues

The majority of countries in Sub-Saharan Africa have witnessed increasing difficulty in matching domestic food production with food requirements. In part this reflects the frequent absence of a coherent policy framework for the traditional food sector, particularly for root crops, and a lack of coordinated efforts to develop these crops (Eicher 1980, FAO 1986). In many cases, policies have tended to focus on cereals in order to meet an escalating urban demand. Policies designed to promote intensive cereal production have often not been successful in many parts of Sub-Saharan Africa where agro-climatic conditions are not suitable for these crops. As a result, the production of cereals has not been able to meet demand, which has led to a growing reliance on cereal imports in order to feed urban populations. This reliance, frequently made greater domestic price policies and exchange rate policies, is absorbing and increasing quantity of foreign exchange, thus inhibiting development initiatives and intensifying poverty and undernourishment.

As a consequence, many countries have recently begun to give increasing attention to the possibilities of expanding supplies of root crops to meet a larger part of the growing urban requirements for high-energy staples (FAO 1986). Although these crops have traditionally been the dietary staples in much of the region, particularly in tropical areas, and continue to be so in many rural areas, they have until recently, been relatively neglected by most policy makers and research institutes. While part of this neglect can be attributed to difficulties in marketing and processing these highly perishable commodities, they have also suffered from being regarded as "backward" or "poor peopole's" crops. It is a reflection of the considerable potential of root crops as abundant sources of energy, as well as their crucial role as staple and famine foods, that development of improved root crop varieties and accompanying technology should receive high priority in the U. S. government.

United States assistance attempts to move countries from low-income to middle-income status. These countries in the process may become exporters of specific agricultural commodities, but net agricultural importers (Anonymous 1986). LRA's have few economic alternatives outside agriculture, thus a major purpose of U. S. assistance to developing countries is to raise the productivity and incomes of LRA's to produce or purchase adequate diets for their families and increase their purchasing power (Anonymous 1986). Because root crops are well adapted to many agro-climatic regions in Sub-Saharan Africa, use minimal fertilizer inputs and do not compete with U. S. agricultural commodities, root crop breeding and associated system, processing, storage and marketing development programs should receive highest priority funding from the U. S. governments. Accelerated production of root crops by LRA's will have a powerfl impact not only on the production of but also on the demand for food because LRA's are likely to spend a high production of increased income from improved root crop technology on locally-produced goods and services generating additional local employment, which in turn, will stimulate additional demand for food and for imported U. S. goods. The net effects of U. S. investment on root crops research in Africa can be expected to assist in achieving food security in

African countries and in increasing U. S. exports of agricultural commodities, chemicals, machinery and other goods.

A major limitation in root crops breeding is the small number of plant breeders available in a country to develop improved varieties for the different agro-climatic zones in the country. The development of trained root crop research teams (breeders, entomologists, plant pathologists, agronomists, etc.) for various agro-climatic zones in each country or region should receive high priority. All donors should increase support of graduate level and technical management training programs of nationals as root crop researchers. Where possible, such training should take place at African universities, IITA and national centers. Follow-up placement programs of the trained nationals should be developed and research teams should work together in specific agro-climatic zones. Because an integrated farming system approach is required for an effective root crop breeding program to reach LRA's, long-term (10 to 15 years) coordinated funding by donors is required (Eicher 1982, Okigbo 1986, U. S. Congress 1984).

Donors should provide funds to strengthen the already existing network developed by ISTRC - AB and ensure that as many root crop workers in Africa, especially women and extension personnel, can participate in ISTRC - AB activities. Funding for the research, training and farming systems components of the IITA - Root and Tuber Improvement Program should receive priority funding from donors. National root crops research centers and African universities should receive more funds from donors for facilities and equipment difficult to obtain because of insufficient foreign exchange, but required for effective root crop breeding programs. Successful cooperative root crop research between IITA and national centers such as the National Root Crop Research Institute - NRCRI

(Nigeria), Cameroons National Root Crop Improvement Program CNRCIP (Cameroons), National Cassava Program - PRONAM (Zaire), Institute DesSciences Agronomiques - ISAR (Rwanda) should be strengthened and expanded to other African countries (IITA 1984, 1985a, 1986). Cooperative research efforts between African national centers and IITA should be strengthened and expanded. Regional root crop research networks should be framed to coordinate and intensify international and national efforts to overcome constraints and increase production (IITA 1986a). Cooperative efforts on root crop research between U. S. universities or USDA programs and IITA, African national centers and universities directed toward assisting the LRA's should be encouraged. The cooperative root crop research recently initiated between IITA and Tuskegee University illustrates the type of U. S. university - IITA linkages that should be further developed (Hill _et_ _al_. 1986).

Technology Potential

It is difficult to predict the time frame necessary for wide adoption of improved varieties considering the varied levels of extension services and limited number of national root crop programs in African countries. However, the few examples of documented examples suggest that adoption of improved root crop varieties can be extensive. The cassava breeding program was initiated at IITA in 1971, and nine years later in Oyo state, Nigeria, about 20% of all cassava lines planted were improved varieties developed by IITA. By 1985 this amounted to about 35,000 hectares (IITA 1981, 1986). Throughout Nigeria 80,000 hectares were planted with five improved IITA developed varieties in 1985. It is projected that 3 million hectares will be planted with improved varieties in 1990. This suggests that roughly 20 years are required to develop and disseminate improved cassava varieties over 3 million hectares. The cassava improvement program in Zaire was initiated in 1974 and in 1984 approximately 2 million meters of improved cassava (enough for 850 ha) were available for distribution to farmers (IITA 1985a). A major problem in distribution of improved varieties has been a shortage of seed material. Thus, mechanisms for rapid multiplication and distribution of improved seed must be developed in each country.

Wider adoption of improved varieties will require national policies and strategies that encourage both production (breeding rapid multiplication and distribution of seed) and consumption (e.g. education about sement) of root crops (roots and foliage). Linkages between extension and root crop research centers should be strengthened. Transport and storage facilities and processing techniques should be improved. Women LRA's in particular should receive training in all aspects of breeding, extension, agronomy, processing and marketing root crops. Where feasible, varieties should be developed for different uses such as home consumption, industrial processing and animal feed.

Cutting edge research includes seed yam minisett and microsett technology, mass rearing and dissemination of natural enemies of cassava mealy bug and spider mite, use of tissue culture for dissemination of improved varieties and screening root crop germplasm for environmental adaptability, mulching for seed yam and ware yam production, development of non-sweet sweet potatoes, development of integrated pest management for control of sweet potato weevils, selection of low cyanide cassava varieties, selection of root crop varieties that promote beneficial root-microbial association (IITA 1985a, 1986).

Potential biotechnical application for root crops include the following: production and inoculum of vesicular-arbuscular mycorrhzal fungi and 2n gamete improvement approach to improve root crops; identification of rhizosphere colonizing N_2-fixing and growth hormone producing bacteria associated with root crops that can be develooped into inoculum to provide nutrition and increase yield; use of cell culture methods for regenerating intact plants from single cells or tissue explants for rapid multiplication of seed and for rapid screening of root crop germplasm for specific character traits; use of genetic engineering to develop biocontrol agents such as microorganisms to control root croop pests, and identification of growth hormone to induce flowering of yam to permit use of non flowering species and clones in breeding programs.

FINAL DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

OTA Technology Paper Series: Pest Control

by

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FINAL DRAFT

ACRONYMS

AID	U.S. Agency for International Development
CAR	Central African Republic
CIBC	Commonwealth Institute of Biological Control
CILSS	Comite Interetats de Lutte Contre la Secheresse au Sahel
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
DLCO/EA	Desert Locust Control Organization for East Africa
EEC	European Economic Community
FAO	Food and Agriculture Organization of the United Nations
IARCs	International Agricultural Research Centers
ICIPE	International Centre of Insect Physiology and Ecology
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
ILRAD	International Laboratory for Research on Animal Diseases
IPM	Integrated Pest Management
IRLCO/CSA	International Red Locust Control Organization for Central and Southern Africa
OAU	Organization of African Unity
OCLALAV	Common Organization for the Control of the Desert Locust and Grain-Eating Birds
OICMA	International African Migratory Locust Control Organization
OTA	Office of Technology Assessment
PVOs	Private and Volunteer Organizations
RFCP	Regional Food Crop Protection (Project)
WARDA	West Africa Research and Development Association

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1. ABSTRACT

1. Pests and pesticide use in sub-Saharan Africa form a massive problem. Present losses caused by pests are enormous, and national programs in quarantine, crop protection, and pesticide regulations are generally ineffective. To avert the losses, farmers are using increasing amounts of chemical pesticides. Pesticide use is encouraged by government subsidies.

2. Trends indicate that chemical technology is spreading much more rapidly than is the capability to ensure its effective and safe use. Most sub-Saharan countries lack infrastructures required to enforce pesticide laws and teach farmers how to use pesticides correctly and safely.

3. Actions that encourage comprehensive pest management systems, synchronized with and integrated into optimal agricultural systems, will be required to halt the losses and increase and maintain crop yields. Simultaneously, new pesticide regulations, enforcement procedures, and training programs are needed to curb the growing pesticide problem.

4. Implementing effective pest and pesticide management programs uniformly across the entire sub-Saharan region could take a minimum of ten years even under the best of conditions. Quicker results would be expected in countries such as Kenya that already have relatively well developed infrastructures in pest and pesticide management.

5. There is critical need to reduce pest losses and to reverse the trend toward increasing reliance on chemical pest control in sub-Saharan Africa. More durable, less expensive, and safer integrated pest management systems are needed. The U.S. has helped and can continue to help even more through cooperative research, technical assistance, increased support for extension and farmer education, and changes in development assistance policies.

2. PEST CONTROL TECHNOLOGY AND PRACTICES

6. A wide range of insects, mites, fungi, bacteria, viruses, weeds, vertebrates, and other pests plague low-resource farmers in sub-Saharan Africa. The pests interfere with the production and utilization of crops and livestock, transmit human diseases, and reduce the quality of the environment.

7. Annual pest losses incurred in the field and in storage are enormous, estimated at 30 percent or more of the potential production of some crops (Cramer, 1967; Pimental, 1978; Barr et al., 1975). In some years, major pest outbreaks may completely destroy crops on individual farms. Armies of locusts and grasshoppers such as appeared in much of Africa in 1986 (Walsh, 1986a) have the potential of devastating crops over vast areas.

8. Pests of public health and livestock also present a serious problem. Malaria persists as the most important infectious disease in sub-Saharan Africa despite attempts to

control the vector mosquitoes with insecticides and massive programs for the distribution of antimalarial drugs (Molineuax and Gramiccia, 1980). The two major arthropod-born diseases of livestock, trypanosomiasis (transmitted by tsetse flies) and East Coast fever (transmitted by ticks), prevent livestock production in vast areas of the region (Harwood and James, 1979).

9. The principal techniques and practices for controlling pests in sub-Saharan agriculture include:

10. Quarantines: regulatory techniques to prevent entry and establishment of new pests in a country or area. Examples of recent foreign pest introductions in Africa are the cassava mealybug (*Phenacoccus manihoti*) and cassava green mite (*Mononychellus tanajoa* complex). Accidentally introduced into Africa from South America in the 1970s, these pests now infest over 60% of the cassava growing area of Africa and cause losses estimated at nearly $2 billion per year (Hahn and Keyser, 1985). Although quarantine programs do not guarantee against introductions of pests, if properly implemented they reduce the threat of accidental introductions such as these.

11. Host resistance: utilization of varieties of plants and animals which are resistant, tolerant, or unattractive to the pest. Host resistance is one of the most effective, easiest, and most economical means of controlling insects and plant diseases. Improved lines of cassava with resistance to the African cassava bacterial blight (caused by *Xanthomonas campestris* pv. *manihotis*) have been developed by the International Institute of Tropical

Agriculture (IITA). Several IITA-improved lines give yields up to 30 tons per hectare (Leuschner, 1978) and have outyielded local standard varieties by 2-18 fold (IITA, 1976), primarily due to their disease resistance.

12. Cultural control: alters the environment so it is less favorable for the pest or more favorable for the pest's natural enemies. One of the oldest and most successful methods of pest suppression, cultural control can be simple, inexpensive, and easily adopted by individual farmers. In Kenya, for example, farmers, recognizing the link between field fertility and Striga weed, use crop rotations and fertilization with manure to control this parasitic plant affecting cereal grains (Conelly, 1985).

13. Biological control: involves either the propagation and release of new natural enemies against target pests or the encouragement of practices that preserve and increase the effectiveness of those natural enemies already present. This technique is having success in reducing the cassava mealybug in part of its range in Africa. Since 1982, a parasitic wasp Epidinocarsis lopezi, imported from South America, has been released at 30 different sites, comprising roughly 9% of the total cassava in Africa. The parasite has successfully established in most of the release sites and is spreading to other areas. In Nigeria, where it has been studied most intensively, the parasite has spread widely from the release sites and in each new area has reduced the mealybug population to non-injurious levels. The parasite will now be released in other

mealybug areas of Africa as part of a $20 million biological control program (Development International, 1986; IITA, 1984; CABI, 1986).

14. Pesticides: chemical agents used to kill or in some other way diminish or stop the actions of pests. A primary benefit of a pesticide is that it can be marshalled quickly to give rapid control of a threatening pest. The results are often spectacular. For example, applications of the insecticide permethrin to cowpea in Nigeria reduced the target insect pest populations (several species) 50-85 percent; the treated cowpea produced seven times more peas than the untreated cowpea (Matteson, 1982).

15. Integrated pest management (IPM): a pest control system that integrates two or more pest control techniques or practices to give the "best mix," based on criteria of crop yield, profit, and safety (Kenmore et al., 1985). Pesticides, if used, are applied only as required to keep a pest from surpassing an injury level predetermined from regular monitoring and assessments of pest damage potential. IPM promises to decrease dependency on pesticides, reduce pest losses and costs of control, and help to stabilize yields (Matteson et al., 1984; Usenbo, 1976).

3. STATUS OF PEST CONTROL

General Patterns

16. There is presently no way to determine accurately the kinds and levels of use of the various pest control techniques and practices in sub-Saharan Africa. Surveys of specific use

patterns of the techniques and practices have been limited to a few areas in the region. Table 1 shows general use patterns in the region.

Table 1--General Patterns of Use of Pest Control Techniques and Practices in Sub-Saharan Africa

Tech./Practice	Geographical Spread	User Group
Quarantines	Most countries have quarantine legislation; few have resources to enforce properly	Maintained by governments at ports of entry
Host resistance	Generally effective resistance to native plant diseases and some insect pests in local unimproved varieties. Many improved crops also resistant to one or more pest insects or diseases	Most low-resource farmers and many large enterprise farmers as well
Cultural control	Used widely for control of pest insects, plant diseases, and weeds	Primary method of pest control of low resource farmers; large farmers use less frequently
Biological control	Organized efforts (e.g., against cassava mealybug) limited to exotic pest species. Naturally occurring biological control agents widespread in control of insects and mites	Low resource farmers especially but large enterprise farmers also benefit
Pesticides	Use widespread in region and increasing	Large enterprise farmers use routinely; use by small farmers limited unless participating in subsidized programs
IPM	Several regional and national projects underway, but farmer use still limited	Applicable for both small and large farmers

Source: African Journal of Plant Protection (vols. 1-6, 1980-85), Sasser et al. (1972), Teng (1985a)

17. A number of factors influence the degree to which a pest control technique or practice is used in a given area: the cropping system (subsistence vs. large enterprise, cash vs. food crop, etc.), farmer resources, the country's infrastructure in pest control, donor financial support and pesticide policies, etc. As a general rule, most subsistence farmers still depend heavily if not entirely on traditional methods of pest control (cultural practices, natural resistance in the crop plants, and biological and environmental controls) to protect their basic food crops. They normally use pesticides only if the materials are provided free or at very low, subsidized costs (see paragraph 28), and then usually restrict the treatments to cash crops. By contrast, larger enterprise farmers have abandoned many of the traditional methods of pest control and are using increasing quantities of pesticides. Pesticides are commonly used in plantation cash crops (e.g., cotton, cocoa, banana), vegetables, and high yielding cereal grains (Bull, 1984; PBS, 1981).

More Developed vs. Less Developed Infrastructures

18. The effectiveness of pest control infrastructure and potential for improving pest control practices currently varies widely among countries of the sub-Sahara. A comparison in the infrastructures of Kenya and Central African Republic (CAR) illustrates the wide span of difference. Kenya's infrastructure in pest control, while considerably less endowed than a developed country's infrastructure, represents one of the best in the sub-Sahara. The country has a plant quarantine station, one of the

best biological control facilities in tropical Africa, and a number of research and "outreach" programs aimed at improving systems of crop protection. The International Centre for Insect Physiology and Ecology (ICIPE), located in Nairobi, is one of the major pest management research and training centers in Africa. The University of Nairobi, in collaboration with ICIPE, offers a Ph.D. degree in insect science with an option that emphasizes pest management. The Ministry of Agriculture has a series of training programs which include some pesticide safety training for farmers. IPM is still in its infancy, but the potential for developing IPM programs is quite high. Through funds provided by U.S. Agency for International Development (AID), the U.S. has been a major supporter of ICIPE's program in IPM. Nigeria, Cameroon, and Ivory Coast are examples of other sub-Saharan countries with relatively well developed pest control infrastructures (source: CICP, unpubl.).

19. By contrast, the Central African Republic's infrastructure is one of the most poorly developed. The country has no plant quarantine station, no research staff trained in plant protection, and minimal research facilities. The overall capability for research, extension, and training is poor. According to Teng (1985a), CAR lacks even the basic pest control infrastructure. The U.S. has played a minimal role in support of pest management in CAR. Togo and Somalia are examples of other sub-Saharan countries that lack basic pest control infrastructures (source: Teng, 1985a; CICP, unpubl.).

Quarantines

20. Most sub-Saharan countries have some form of quarantine regulations, but few are effective. A recent FAO study of quarantines in West and Central Africa showed that inadequate training limits the technical capability of the quarantine personnel (Teng, 1985a). Further, regional cooperation among quarantine agencies--essential in preventing the spread of some pests--is strained by political tensions and poor communications.

Host Resistance

21. Plant breeders have bred useful resistance into, or identified resistance sources for, a range of basic sub-Saharan food crops, including sweet potato, yam, cocoyam (species of *Colocasia* and *Xanthosoma*), cowpea, sorghum, maize, rice, millet, and cassava. Recent significant accomplishments in host resistance include development of cassava varieties resistant to the serious mealybug and green spider mite discussed in paragraph 10 (Hahn, 1982). IITA is distributing resistant cassava clones for distribution to farmers in Nigeria, and seeds are being dispatched to national programs throughout Africa.

22. The unimproved native crop varieties (land races) of crops still planted by most subsistence farmers in the sub-Saharan region are not inferior per se and, in fact, may represent the optimum for the conditions where grown. The genetic diversity of these varieties confers at least partial resistance or tolerance to environmental stresses and pest

attack. Although low yielding, the native varieties provide some security and help meet the subsistence farmers' need for survival yields even in the worst years (Jennings, 1976).

Cultural Control

23. Cultural control is as old as agriculture and includes some of the most effective methods for suppressing insects, disease agents, and weeds (Glass and Thurston, 1978). A common cultural practice of low-resource sub-Saharan farmers is intercropping. The greater crop diversity in the intermixed plantings (as opposed to monoculture) is known to increase predator and parasite populations in a given crop (Matteson, 1984). The intermixed system is also known to attract pests away from susceptible crops to nonsusceptible crops. For example, cotton farmers in Nigeria interplant with a diversionary crop of okra which attracts pest flea beetles away from the cotton (Usenbo, 1976). Other traditional sub-Saharan cultural practices known to reduce pest populations include burning undesirable vegetation, planting the crops during pest free times of the year, cultivation to control weeds, and destruction of secondary crop growth harboring pest insects or diseases (Matteson, 1984; Glass and Thurston, 1978).

Biological Control

24. Biological control is a process of reinforcing nature's own system of checks and balances. Traditional agricultural practices, characterized by crop diversity in the form of polycultural systems, encourage natural biological control of

pests (Matteson et al., 1984). Unless disrupted by pesticides or other means, a wide range of biological control agents flourish in the traditional agroecosystems and keep many potential native insect and mite pests in check. This "free" and very desirable form of crop protection has benefited farmers for as long as traditional agriculture has existed.

25. "Classical biological control," which involves propagation and release of new natural enemies, has been limited in Africa to a relatively small number of insect, mite, and weed species of a foreign origin. Where naturally occurring biological control involves no costs and requires no institutional support to maintain, classical biological control involves costs to find, import, rear, and liberate the new natural enemies and requires institutional support to maintain the program. However, classical biological control is clearly highly effective and economical. Worldwide, economic returns from classical biological control programs that have been evaluated were estimated at $30 for every dollar invested (Messenger et al., 1976).

26. The Africa-wide Biological Control Project of Cassava Pests is presently the largest organized effort in biological control in the sub-Saharan region. Set up by IITA in 1980, the Project has been financed by the International Fund for Agricultural Development (IFAD), and other donors, and collaborates with a range of national and international organizations. The Project was responsible for the successful

introduction of the cassava mealybug parasite noted in paragraph 13.

Pesticides

27. Pesticide use in sub-Saharan Africa varies considerably among crops, pests to be controlled, and geographical region. Large plantings of cash crops (cotton, coffee, banana, cocoa, etc.) generally receive the greatest quantities of pesticides, but the chemicals are also used on some food crops, especially the high yielding varieties of cereal grains and vegetables. While there are no quantitative data on use patterns in the region, use is generally increasing throughout Africa. In 1979, GAO estimated that pesticide use in the continent would increase fivefold or more during the decade ending in 1984 (GAO, 1979).

28. Some African countries heavily subsidize pesticide product sales. For example, in Senegal, 90% of all agricultural pesticides are distributed to growers free of charge by crop marketing boards and other agricultural agencies. In Ghana, the rate of pesticide subsidy (percentage of full retail costs) is nearly 70 percent (Repetto, 1985).

IPM

29. In a sense, virtually all subsistence farmers in the sub-Saharan region practice a form of "integrated" control. They depend on a combination of traditional cultural practices that have evolved over long periods of time to suppress certain pests. However, IPM programs, developed through a conscious effort at understanding the pests and factors affecting them, and

implemented in a way consistent with local agricultural and socioeconomic conditions, are in an infant stage.

30. To date, the largest efforts to develop IPM systems for crop pests have been through the CILSS Integrated Pest Management Project and AID's Regional Food Crop Protection (RFCP) Project, both focusing on pest problems of basic crops in the Sahel (the RFCP Project also included Cameroon and Guinea Bissau). Funded by AID, managed by CILSS, and implemented by FAO technical specialists, the CILSS Project (implemented in 1978) was supposed to have generated IPM methodology to be fed into the RFCP Project. In turn, the RFCP Project was to have extended the IPM methodology to national extension and crop protection services in the region.

31. Both projects served to increase attention to crop protection issues and improved Sahelian institutional capabilities in IPM (OTA, 1986). However, as of December 1984, the CILSS IPM Project had not developed one IPM package for the RFCP Project to extend (AID, 1984). The projects suffered management problems that limited their effectiveness (OTA, 1986).

Development Assistance Activities

32. Numerous national, regional, and continent-wide projects in Africa support research, training and education, and operations related to pest control. Table 2 provides examples of major development assistant activities related to pest control in the sub-Sahara.

Table 2.--Examples of Major Development Activities Affecting Pest Control in Sub-Saharan Africa

Tech./prac.	Donor/center	Type of support
Quarantines	OAU	Supports Interafrican Phytosanitary Council
	FAO	Supports locust control programs (OCLALAV, IRLCO/CSA, OICMA, DLCO/EA)
	U.S. and other bilateral efforts	Support individual country efforts
Host resistance	IITA	Resistance in several crops
	WARDA	Resistance in rice
	CIMMYT	Resistance in maize
	ILRAD	Resistance in livestock
	ICIPE	Resistance in cereal crops
	ICRISAT	Resistance in millet and sorghum
	U.S. and other bilateral efforts	Support individual country efforts, ICIPE, and IARCs
	World Bank	Supports individual country efforts and IARCs
Cultural control	ICIPE	Cultural practices in East African crops
	IITA	Cultural practices in root, tuber, and cereal crops
	U.S. and other bilateral efforts	Support individual country efforts, ICIPE, and IARCs
	World Bank	Supports individual country efforts and IARCs
Biological control	CIBC	Exploration and introduction of natural enemies
	IFAD	Africa-wide Biological Control Project

---Continued---

Table 2.--Examples of Major Development Activities Affecting Pest Control in Sub-Saharan Africa

Tech./prac.	Donor/center	Type of support
Biological Control	IITA	Biological control of cassava pests
	ICIPE	Biological control of insect pests of East African food crops
	U.S. and other bilateral efforts	Support individual country efforts, ICIPE, and IARCs
	World Bank	Supports individual country efforts and IARCs
Pesticides	FAO	Supplies pesticides in emergency situations
	World Bank	Supports pesticides in development projects
	U.S. and other bilateral donors	"
	EEC	"
IPM	ICIPE	Research and training
	FAO	CILSS IPM Project
	AID	CILSS IPM Project, individual country IPM projects, and ICIPE
	Other bilateral donors	Individual country IPM projects
	World Bank	Individual country projects

Source: Addoh (1979), Smith and Bottrell (1983), Repetto (1985), OTA(1984), CGIAR (1984), Teng (1985a), ICIPE (1983), Bull (1982

Constraints

33. Even the best pest control technique or practice will fail under certain conditions. Some of the technical limitations and socioeconomic constraints are listed in Table 3.

Table 3.--Some Limitations to Pest Control Techniques and Practices in Sub-Saharan Africa

Tech./prac.	Limitations
Quarantines	-Will not provide protection against native pests or established foreign pests -International cooperation essential
Host resistance	-Disease agents and insects may evolve strains or biotypes to overcome resistance -Generally used only for control of insect pests, pathogens, and nematodes -Farmers may have difficulty accessing new resistant varieties initially
Cultural control	-Some cultural controls require high labor inputs -Some (e.g., burning, tillage) may result in loss of soil organic matter and accelerate erosion
Biological control	-Generally used only for insect and mite control
Pesticides	-Countries may lack the foreign currency to maintain adequate supplies of effective chemicals and application equipment -Difficult to apply properly -Health and environmental hazards
IPM	-Highly site specific -Relatively high labor input required -Crops must be monitored regularly and decisions made about need for remedial action

Source: Bottrell (1983), Teng (1985a,b), IOBC (1981), Reichelderfer and Bottrell (1985), Kenmore et al. (1985)

34. Institutional constraints also slow development of effective pest and pesticide management programs. A number of sub-Saharan countries lack even basic infrastructures in pest and pesticide management. While others have the basic infrastructures, they often lack resources and personnel necessary to make them effective (M'Boob, 1984; Teng, 1985a). Of fifteen countries included in Teng's (1985a) survey of plant protection in west and central Africa, five had no pesticide laws and three had no organized research program in crop protection. Teng's (1985a) study, summarized in Table 4, showed that sub-Saharan countries are generally weak in a number of critical areas of plant protection and lack adequate numbers of specialists in this field.

Table 4.--Strengths of Fifteen West and Central African Countries in Various Areas of Plant Protection

Area of Plant Protection	% of countries in category Good	Moderate	Poor	No Inf
Plant protection personnel	7	40	46	7
Pest control equipment	0	47	47	6
Support facilities	0	13	80	7
Plant protection laboratories	0	47	47	6
Pest diagnostic laboratories	0	47	47	6
Plant quarantine buildings, equipment	7	40	40	13
Pesticides available locally	0	43	20	27
Plant protection service	7	20	40	33
Agricultural schools, training facility	7	66	20	7
Specialized plant protection curriculum	7	33	53	7
Institutionalized research	7	53	20	20
On-farm, applied research	0	13	74	13
Pest lists	13	47	33	7
Pest distribution knowledge	0	47	40	13
Pest biology knowledge	7	7	13	73
Economic Loss knowledge	0	27	40	33
Pest control knowledge	0	20	80	
Overall strength				
*Extension	7	40	40	13
*Research	20	54	13	13
*Training	7	46	40	7

Source: Teng (1985a). Countries in survey were Benin, Cameroon, Central African Republic, Congo, Gabon, The Gambia, Ghana, Guinea,Guine Bissau, Ivory Coast, Liberia, Nigeria, Sierra Leone, Togo, and Zaire

35. Trends indicate that chemical pesticide technology is spreading much more quickly in Africa than is the capability to ensure its effective and safe use. Many pesticides considered too dangerous for restricted use in the western nations are being exported from these nations to countries throughout developing areas of Africa and elsewhere (Bull, 1982; Bottrell, 1984). Many sub-Saharan countries lack infrastructures for properly governing importation, domestic use, and disposal of these pesticides. Of fifteen west and central sub-Saharan countries included in Teng's (1985a) survey, five had no laws to govern the importation or use of the materials. Six had enacted laws. The survey failed to determine the situation in the remaining countries.

36. Even with pesticide laws, most sub-Saharan governments lack personnel and resources required to enforce them. Further, the region's farmers are seldom prepared to handle the chemical substances. Often they cannot read or understand the pesticide labels, or they use pesticides sold in unlabelled containers. They rarely possess (or wear) protective clothing or safety devices and may carelessly dispose of left over materials. The sub-Saharan countries usually lack medical personnel and facilities for diagnosing and treating cases of pesticides, and educational efforts on pesticide safety are generally poor (Bull, 1982; M'Boob, 1984).

37. Pesticide use is encouraged by subsidy programs noted in paragraph 28. The pesticide subsidies allow farmers to access pesticides free or at very low costs, and they may therefore

encourage unnecessary use. Further, the subsidies may discourage farmers from using alternative methods and also impede institutional efforts in IPM (Repetto, 1985).

4. APPLYING OTA'S PRINCIPLES AND CONCEPTS

38. Table 5 applies OTA's principles and practices to pest control needs in low-resource agriculture in sub-Saharan Africa.

39. Principle A emphasizes comprehensive integrated pest management systems synchronized with and integrated into optimal agricultural systems. Akin to this principle, Principle G recognizes sustainability as a key argument for IPM and against reliance on unilateral chemical control programs. A systems approach involving cooperation of a range of disciplines is needed to ensure proper synchronization and integration. The International Agricultural Research Centers (IARCs), ICIPE, and many national institutions possess much of the required expertise. U.S. universities experienced in developing holistic IPM systems can contribute by assisting these institutions develop programs that emphasize the systems approach to pest management.

40. Principle B emphasizes the importance of linking local, national, and international institutions and improving communications between farmers, research personnel, and extension officers. In countries where operating conditions are adequate, computer-driven telecommunication systems can be used to improve communications between research and extension workers. Radios can be used to improve communications between extension workers

and farmers.

41. Principle C emphasizes low-input durable systems of pest management and new pesticide enforcement procedures. Pest management systems that draw heavily from host resistance, cultural control, and biological control reduce risks associated with pests and pest control practices. The IARCs, ICIPE, FAO, and Commonwealth Institute of Biological Control (CIBC) are an important resource for national institutions in charge of developing the low-input systems. AID, other donors, and FAO can contribute significantly in efforts to strengthen pesticide legislation, enforcement procedures, and safety.

42. Principles D, E, F, and H emphasize the importance in understanding and supporting local methods and social structures. The studies and other actions recommended are necessary before "best mix" pest management systems can be structured for a given user group. Drawing from local resources, and encouraging the participation of women, Peace Corps Volunteers residing in local villages, and Private and Volunteer Organizations (PVOs) familiar with local customs, will increase chances for successful understanding and transfer of pest control technology.

Table 5.--Application of OTA's Principles and Concepts
Pest Control

Principle A: Components

1. **What Needs to be done**

   -Emphasize comprehensive multi-pest management systems that optimiz inputs and synchronize with the overall farming-livestock operatio

2. **How to do it**
   -Donors should emphasize IPM in all agricultural development projec
   -Increase research and training in IPM and systems approach
   -Approach pest control with interdisciplinary team expertise that emphasizes agroecosystems analysis
   -Establish socioeconomic criteria for use of pest control technique

3. **Who should do it**
   -IARCs, ICIPE, and national institutions with cooperation from U.S. universities

4. **What limits it**
   -Pesticide subsidies
   -Weak government infrastructures and financial support
   -Short-term and often conflicting objectives of donors

Principle B: Linkages

1. **What Needs to be done**
   -Link local, national, and international institutions and improve communications at farmer-research-extension level

2. **How to do it**
   -Form sub-Saharan crop-pest networks
   -Increase libraries, scientific exchanges, and telecommunications
   -Organize regionally coordinated IPM demonstrations for farmers and extension personnel

3. **Who should do it**
   -IARCs, ICIPE, national institutions, and Peace Corps Volunteers

4. **What limits it**
   -Weak government infrastructures, lack of resources, and limited understanding of principles involved

Principle C: Minimizing Risk

1. **What Needs to be done**
   - -Emphasize low-input, durable systems of pest management, and strengthen pesticide enforcement procedures

2. **How to do it**
   - -Increase research, extension, and demonstration efforts in host resistance, biological control, cultural control, and IPM systems
   - -Develop early-warning systems for locusts and other migrant pests
   - -Donors adopt uniform pesticide guidelines
   - -Assist national institutions enforce pesticide legislation

3. **Who should do it**
   - -IARCs, ICIPE, national institutions, and CIBC (research and demonstrations)
   - -FAO and locust control agencies (early-warning systems)
   - -AID, other donors, and FAO (pesticide legislation)

4. **What limits it**
   - -Limited resources, pesticide subsidies, and lack of cooperation

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Principle D: Local Resources

1. **What Needs to be done**
   - -Characterize local pest control practices

2. **How to do it**
   - -Conduct socioeconomic surveys on low resource farms within tribes

3. **Who should do it**
   - -IARCs, national institutions, ICIPE, and U.S. universities

4. **What limits it**
   - -Limited funds
   - -Not a high government priority

Principle E: Heterogeneous Groups

1. **What Needs to be done**
   -Determine perception of pests, pesticides, and nonchemical methods relative to age, gender, ethnic group, economic status, and specific crop-livestock system

2. **How to do it**
   -Socioeconomic surveys and graduate research

3. **Who should do it**
   -African universities, U.S. universities, IARCs, and ICIPE

4. **What limits it**
   -Lack of funds

Principle F: Women

1. **What Needs to be done**
   -Increase role of women in all phases of pest control initiatives

2. **How to do it**
   -Conduct train-the-trainer programs for women at the village level within tribes
   -Increase jobs for women in extension and other government services

3. **Who should do it**
   -National institutions, Peace Corps, and PVOs

4. **What limits it**
   -Limited numbers of women in government services

Principle G: Sustainability

1. **What Needs to be done**
   - Adopt national policies to encourage long-term programs in sustainable agriculture

2. **How to do it**
   - Evaluate traditional, historically successful sustainable methods
   - Realign existing research to emphasize comprehensive resource optimization of pest control input
   - Institutionalize pest management in government agencies that emphasize sustainability

3. **Who should do it**
   - National institutions with assistance from IARCs

4. **What limits it**
   - No unified policy; low government priority
   - Increasing pesticide use

Principle H: Local Participation

1. **What Needs to be done**
   - Determine opportunities for developing pest management systems from local human resources and materials

2. **How to do it**
   - Inventory and determine efficacy of local botanical pesticides, biological agents, and cultural methods
   - Determine feasibility of local pest control cottage industries

3. **Who should do it**
   - IARCs, national institutions, and PVOs

4. **What limits it**
   - Lack of funds and low government priority

5. KEY POLICY ISSUES

Constraints

43. While science and technology have recently increased yields of a number of crops in the sub-Saharan region (OTA, 1984), the genetic base of some crops has rapidly narrowed (Buddenhagen and de Ponti, 1983). Planting genetically uniform high-yielding varieties over large areas can result in new vulnerability to pests.

44. Without alternative actions, pest problems can only be expected to worsen in agricultural areas being developed and modernized. Historically, as agriculture intensifies, so does potential for pest problems.

45. The tendency in the development schemes has been to devise short-term pest control solutions that ignore long-term interactions and effects. Chemical pesticides have provided the quick solution.

46. U.S. exports account for about 16.5 percent of the world pesticide export market. The European Economic Community (including the U.K.) is the major exporter, accounting for 61.5% of the global export market (UN, 1978). A significant--but currently unknown--portion of the exported pesticides end up in Africa. According to a Farm Chemicals (1985) survey of pesticide companies, the trend of exporting pesticides to developing countries is expected to continue. The companies in the survey pointed to increased marketing opportunities in the developing countries.

47. About 25 percent of all pesticides exported from the U.S. are heavily restricted compounds or compounds that have been suspended or prohibited from use in the U.S. (GAO, 1979).

48. Apart from the concern over health and environmental impacts, increased pesticide use is being challenged by the growing problem of genetic resistance in pest organisms. In 1986, NAS (1986) reported that, worldwide, 447 species of insects and mites, 55 species of weeds, at least 100 species of plant pathogens, 2 species of plant-attacking nematodes, and 5 species of rodents were known to possess strains resistant to one or more previously effective pesticides. Resistance has appeared in many serious pests affecting agriculture, livestock, and public health in Africa.

49. The pesticide problem in Africa and other developing areas has come about because of an error in transfer of technology. Modern pesticide technology developed by and for use in the developed world has been exported to areas where the cultures and social structures are not prepared to absorb this technology (Bottrell, 1983). Pesticide subsidies further encourage spread of the technology.

50. Curbing the export of unregistered or highly hazardous pesticides from industrialized nations would be an important step in reducing the problem. However, this is not easy, especially since it goes against the doctrine of laissez faire.

51. Pests and pesticide use in sub-Saharan Africa form a massive problem. Solutions must be sought at the national,

regional, and international levels. Donor governments and non-government organizations can play an important role, by providing some of the information, research, technical assistance, and training required to boost the sub-Saharan efforts. But, ultimately, it is up to the local governments to develop programs best suited for their cultures and social structures. They must recognize long-term pest management as a high priority matter and implement quarantine, research, and education programs that aggressively tackle the overall pest and pesticide problem.

Opportunities

52. Despite present seriousness of pests and pesticide problems in the sub-Sahara, there are encouraging trends. Recent success in preventing a locust and grasshopper scourge in much of the continent serves as a good example.

53. As late as August 1986, locusts and grasshoppers were expected to destroy the crops of tens of millions of Africans. Reuter news agency warned of an invasion of "biblical proportions." However, by the end of October, cooperation and technology had been generally successful in protecting crops in the affected region. Insecticide spraying by aircraft averted serious crop losses. In Senegal, for example, crop losses were kept to about 5 percent (Walsh, 1986b).

54. Other recent encouraging developments relate to FAO's International Code of Conduct on the Distribution and Use of Pesticides and World Bank's Guidelines for the Selection and Use of Pesticides in Bank Financed Projects and Their Procurement

when Financed by the Bank. The FAO Code sets forth procedures on distribution and use of pesticides for governments of exporting and exporting nations to adopt voluntarily. The purpose of the World Bank Guidelines is to prohibit use of highly toxic pesticides and unsafe pesticide practices in Bank financed projects. It is too early to determine the impact of either the FAO or the Bank initiative (both were implemented in 1985), but both the Code and the Guidelines represent a rational step toward mitigating the pesticide problem in sub-Saharan Africa.

55. AID's policy on pesticide assistance, implemented in 1978, is another important development. Part 216 of Regulation 16 of the Federal Code of Regulations, requires a risk-benefit evaluation of agricultural pesticides proposed for use in AID's development assistance projects. The regulation normally prohibits the purchase of pesticides which are not sold or which are severely restricted in the U.S. It encourages the use of non-chemical methods and IPM systems. While its overall impact has not been documented, the regulation has greatly reduced use of highly toxic pesticides in AID projects (Bottrell, 1984). In addition, it has been a major influence in sensitizing AID project personnel to the advantages of IPM.

56. The AID-financed CILSS IPM Project and RFCP Project (see paragraph 30), despite management problems that limit their effectiveness, have served to increase attention to pest management issues and improved Sahelian institutional capacities in IPM.

57. The IARCs have played an important role in developing improved crops with pest resistance characteristics. They, FAO, ICIPE, and other international organizations in Africa are valuable resources for the national institutions responsible for advancing IPM tactics and systems.

Caution

58. Development and implementation of sociologically, economically, and environmentally sound pest control policies and programs will be a major undertaking. Meeting the challenge will require a "new way of doing business" for those accustomed to working isolated in their own disciplines. They must learn to work with other disciplines in units of holistic-program-oriented teams. Further, they must be willing to recognize that improved pest control is not a guarantee to the larger sub-Saharan problem. Social, economic, and ecological issues, problems of deforestation, human population growth and health, crop storage and marketing, and many other problems must be tackled. Although the IARCs and other international centers can contribute significantly, they can only be effective where adequate national infrastructures exist. As discussed in paragraph 34, the national programs in plant protection are now generally weak.

59. IPM represents an important trend toward a more rational approach to the management of pests and pesticides. But one of IPM's limitations relates to its site-specific nature. Each IPM program has to be tailored for the particular group of users. To be successful, the whole effort, from the time the initial

research is performed through implementation, must evolve as a true partnership between farmers, research personnel, and extension officers. It has been shown many times that this farmer-field approach to research and extension is essential in accelerating the adoption of IPM technology. The sub-Saharan countries presently put minimal emphasis on the farmer-field approach (Teng, 1985a).

60. While IPM generally reduces dependency on pesticides, it cannot be expected to eliminate them. Chemical pesticides will continue to be valuable in the control of many pests. New pesticide management programs will be necessary to ensure that the materials are selected and used properly.

Needs and Roles to be Played

61. African countries must assign pest and pesticide management a high priority; IARCs and other international centers must assist with the research and extension; and donors must provide financial support and cooperate in establishing uniform policies and guidelines which encourage safe use of pesticides.

62. The U.S. has helped and can help even more through cooperative research, technical assistance, increased support for extension and farmer education, and changes in development assistance policies. AID's role is especially important in supporting these efforts. The Agency, in cooperation with World Bank and other donors, should take a lead in advancing IPM and sound pesticide management policies and programs in the region.

63. The Peace Corps can also help, especially at the village

level. With proper training, the Volunteers could assist in conducting pest surveys, crop loss assessments, and farmer education and demonstration programs. Presently, new Volunteer recruits receive minimal, if any, in-service training in pest and pesticide management. Therefore, new training programs for the Volunteers will be necessary.

64. Successful IPM depends heavily on field research, farmer demonstrations, and communications. IPM research personnel must utilize the farmers' fields for much of their experimental work. Extension personnel must organize demonstrations of new practices in these same fields and extend the demonstrations to other areas where conditions are similar. In some areas, where infrastructures permit, computer-driven telecommunication systems may also be important in transferring information. The computer systems could be used to extend information from one research or extension center to another and to create information networks on pests, pesticides, pest management systems, etc. U.S. universities should assist in the research, demonstration, and communication initiatives through cooperative research, technical assistance, and training.

6. SPECULATING ON THE POTENTIAL

65. In deriving the following speculations, it was assumed that the initiatives in Table 5 would remove the constraints discussed under Key Policy Issues.

Regional Level

66. Implementing effective pest and pesticide management

programs uniformly across the entire sub-Saharan region would take many years even under the best of conditions. Some countries in the region (e.g., Central African Republic) would be starting from a very meager infrastructure in pest and pesticide management. In these countries, it may take ten years or more just to create an organizational structure capable of launching an effective long-term effort in pest and pesticide management.

Specific Level

67. Quicker results would be expected in countries such as Nigeria with greater government and scientific resources. Pesticide enforcement procedures and improved quarantine programs could be in place within a year or two. Work toward developing IPM programs in selected crops could begin immediately, drawing from existing scientific knowledge and farmer experience and practices. Within five years, 10-20 percent of farmers of specific crops such as rice (where a rich knowledge base already exists) could be using partial IPM packages. Within ten years, 50 percent or more of the farmers could be using IPM technology.

Regional Changes

68. In paragraphs 66 and 67, it is assumed that the governments will recognize pest and pesticide management as a high priority and research, extension, and operations personnel are committed to advancing new programs in the shortest time possible. It is also assumed that the present policies of pesticide subsidies will be changed to favor farmer adoption of effective alternative methods and IPM systems. Finally, it is

assumed that local resources will be integrated into all aspects of the technology development and transfer and that effective communication networks are encouraged.

"Cutting-Edge" Research

69. A boosted research effort is needed to collect the information and perfect the monitoring techniques required for implementing effective low-input systems of pest control. Holistic-program-oriented teams, working in units and composed of traditional pest management disciplines (entomologists, plant pathologists, weed scientists, and others), system scientists, basic biologists (ecologists, taxonomists, geneticists, and others), and economists and other social scientists are required for this research. A high priority should be to find and evaluate on farmers' fields low-input nonchemical alternatives for use in multi-tactical IPM systems.

70. Research in biotechnology may be important. Genetic engineering techniques, for example, offer a potentially effective and rapid means for conferring insect and disease resistance in crops. Research leading toward the development and validation of crop growth and pest simulation models is important in mapping optimal strategies. The models could be useful aids in determining the proper combination of inputs to achieve effective long-term pest management solutions for a particular socioeconomic setting.

High Technology Methods

71. Telecommunication networks have special promise for

information dissemination. As noted in paragraph 40, computer-driven telecommunication systems could be used to extend knowledge from one center to another and to create information networks on pests, pesticides, and pest and pesticide management systems.

72. Microcomputers have many other important applications in sub-Saharan efforts in pest management, e.g., training, literature searching, data analysis, and simulation studies. A number of U.S. universities are currently developing software that, with appropriate modification, would be applicable in the region.

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FINAL DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

OTA Technology Paper Series: Post-harvest Technology

by

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FINAL DRAFT

OTA TECHNICAL AND POLICY PAPER SERIES: POST-HARVEST TECHNOLOGY

SUMMARY

Post-harvest technology, as applied to staple food crops of low-resource farmers in Africa, is described. Reduction in food wastage and in laborious and tedious work for women are prime aims. Traditional post-harvest operations including threshing, shelling, drying, storage and processing are outlined together with a variety of improved techniques. The post-harvest technology of artisanal fisheries is also referred to and described as small, poor and dispersed but well organised with a sophisticated and complex marketing system in which women play a dominant role. One of the most important needs of the low-resource farmer, that for fuel to redress the scarcity of the traditional fuel, firewood, is stressed and alternatives suggested. It is stated that the development of more efficient energy sources would be invaluable for many post-harvest operations.

Throughout this review mention is made of the contribution of various aid agencies to the development of new technology. Improved technology in post-harvest operations supports the development of low-resource agriculture. There are many other improvements needed in the daily life of such farmers. Therefore, all those requirements should be considered by development agencies, who should aim for an integrated approach in their programmes. Examples are given of the constraints experienced by donor agencies in the application of new technology to food processing, fisheries, aquaculture and food storage. Such evidence reinforces the need for a comprehensive appraisal in developmental work of this kind.

African women grow most of the continent's food. The daily round for them is one of time consuming tasks and considerable labour. Developments in post-harvest technology, such as food preparation, can radically improve their situation on a daily basis and improve their income. However, to be successful, the strategy employed should be a holistic one. The situation of these women should be studied. Appropriate changes in technology should be selected and applied within a self-help framework. Follow-up studies are necessary. A variety of aid agencies exist through which this developmental process can be sensitively advanced.

INTRODUCTION

1. Africa can be broadly divided into zones based on temperature, altitude and the availability of water (Fig. 1). These conditions, together with other factors, such as soil type for example, determine land use and the type of crops grown. In the arid/semi-arid zones the major crops cultivated by the low-resource farmer are cereals like millet and sorghum and legumes such as cowpeas and groundnuts. A wider variety of crops can be grown in the seasonally humid zone and here the staples of the farmer are sorghum, cassava and maize together with various legumes including groundnuts. Farmers in the continuously humid areas are able to cultivate a diverse range of crops including rice, maize, cassava and other root crops and oilseeds. In the highland areas the main food crops of the farmer are cereals, such as wheat, maize, teff and barley, while tea and coffee are important cash crops. Many other crops are grown, including fruit and vegetables, but only the most important staples will be discussed here.

2. In most African countries farming is the major occupation and a large percentage of the total harvest remains on the farm providing the staple diet of the farmer. The post-harvest technologies which are adopted for the harvesting, drying, storage and processing of crops show specific adaptations according to the type of crop within its agroclimatic region. The traditional technology which has been developed by the farming community meets certain basic criteria. The overall factors which influence selection of a particular technology are: the size of the farming enterprise, the reliability of the harvest, the ease with which crop drying can be achieved and the end use of the grain (or opportunity to market a surplus). Most of the work involved in post-harvest operations is extremely laborious and time consuming. In addition, post-harvest losses of food crops may be considerable and are dependent not only on climate and pests,

but also on the methods used for drying, storing and processing. Improved technology has been introduced into the different stages of post-harvest treatment of crops. Its aim is to alleviate the physical effort required and to make these operations more efficient. The most successful technology is that which is based on, or is an improvement of, the traditional practices. It also recognises the fact that traditional practices are already extremely well adapted to existing conditions and are obviously appropriate and acceptable to the farmer. Technology for the post-harvest treatment of the above-mentioned food crops will be described and, although by no means exhaustive, will give an indication of the available technologies and the significant advances that have been made.

3. In some African countries 80% of all agricultural workers are women and, in many countries, they are totally responsible for all post-harvest activities as well as growing the family's food and are often responsible for husbandry. Where surplus crops are marketed this also is the responsibility of the women. Fisheries provide an important source of food and income and here too, responsibility for processing, transport and marketing normally lies in the hands of women.

DESCRIPTION AND STATUS OF POST-HARVEST TECHNOLOGY

Harvesting, threshing and shelling

4. Techniques for harvesting millet and sorghum, the primary food crops of the arid and semi-arid tropics have changed little in comparison with those for other cereals. They ripen in a dry season and may be left standing in the field to be harvested and threshed as labour is available. This procedure can result in losses due to birds eating the ripened grain off the head unless bird-proof varieties are grown. The introduction of simple machines to speed up the threshing would seem opportune but such a propos-

ition needs to consider the social consequences of reducing the opportunities for employment of women as threshers and gleaners. Cassava, the main staple of farmers in parts of the continuously humid areas, is traditionally left in the ground until required. Although this allows the crop to be harvested over a long period, much valuable agricultural land remains occupied and cannot be used for other purposes.

5. Rice is still harvested by hand on small farms in the humid areas. The traditional threshing techniques of trampling by foot or of hitting the rice straw against a hard surface through which the grain falls are wasteful as not all the grain is separated and some may be damaged. In addition, although these techniques cost little they are time consuming and laborious and the trampling causes injuries to the feet. Improved techniques of rice threshing using small rotary threshers are in use in the rice-growing countries of West Africa. Basically, these foot-operated threshers consist of a wooden or metal cylinder, surrounded with teeth or spokes, fitted into a wooden shaft. As the woman pedals the cylinder rotates with the teeth or spokes separating the grains which fall onto a mat or into a container. This technique allows the hands to remain free to feed the thresher and is considerably faster than the traditional method. Wastage is reduced as the stalks can be refed. These pedal-type threshers may be unsuitable, however, in certain areas of West Africa where custom forbids women to sit astride. Several different types of rotary threshers are in use in West Africa including a treadle-operated one introduced by the Volunteers in Technical Assistance (VITA). Where draught animals are available they can be used to draw a simple thresher consisting of rollers with metal blades fitted into a wooden frame over rice stalks. Output is increased compared with the traditional methods and has the advantage of not requiring the rice stalks to be collected into bundles.

6. Maize is the staple food in much of sub-Saharan Africa. Traditionally small quantities are shelled by hand which is laborious and tedious but efficient as damage to the grain is minimised. Larger quantities of grain are shelled by placing the cobs in a sack and beating this with a stick. An improvement on these traditional methods is the use of various types of hand-held shellers. The Tropical Development and Research Institute (TDRI) has developed one such wooden sheller (Fig. 2). This tool is simple and inexpensive and can be made locally using available materials. It is suitable for daily requirements but has the disadvantages of being tiring if used extensively and only shelling cobs of a standard size. This simple device is in use in many countries and several thousands have been distributed.

7. Different types of rotary sheller are available. Basically, the cob is stripped as it is drawn into the machine between a rotating spiked wheel or disc and the body of the machine. These hand-operated machines are usually made of wood or cast iron and are relatively expensive to manufacture. They are, however, efficient, simple and easy to maintain. The small rotary shellers are probably the most suitable for low resource farmers and this type of sheller is being introduced into rural areas of Kenya by the United Nations International Children's Emergency Fund (UNICEF). A survey carried out in Swaziland by TDRI showed, however, that despite the introduction of the improved technology for shelling, farmers prefer the traditional methods as damage and losses can be kept to a minimum. Only when large quantities required shelling were the hand-operated machines preferred.

Drying and storage

8. Before storage all food products must be dried properly. This is necessary to prevent deterioration and is particularly important in inhibiting grain germination, preventing the growth of fungi and bacteria and

reducing insect infestations. Equally important, crops should not be over-dried since this causes breakage, discoloration, scorching and reduces the nutritional value. There are many different techniques for drying and the choice of an appropriate method is dependent on several factors, such as climate, quantity, intended final use of food product and the availability of fuel. For most staple food products the basic methods available to the low-resource farmer are sun and air drying, but artificial drying is necessary when crops are harvested during the wet season.

9. Traditionally grains such as rice, millet and shelled maize are simply spread on the ground and left to dry in the sun. This process can be speeded up by placing the grains on a black plastic sheet which increases the air temperature. The TDRI demonstrated that this process is also effective for root crops such as cassava. By laying cassava on a black surface drying times could be reduced by 25% because of the increased temperatures. In the humid areas of West Africa much maize matures during periods when rain showers and high humidity occur. After harvesting the maize cobs require rapid drying in order to prevent spoilage. This is simply achieved in drying cribs which provide shelter from the rain and allow ready ventilation through open sides (Fig. 3). Improved drying cribs have been designed by the African Rural Storage Center in Nigeria. These are well ventilated and, when an insecticide is applied to the maize, found to be very effective in reducing losses due to insects. In some regions the farmer is encouraged to grow improved, high yielding varieties of maize. This practice may permit double cropping of the land but it is also likely to bring the problem of the maize maturing in a season when sun and air drying are inadequate so that some artificial drying is essential. A suitable dryer for the low-resource farmer consists of a clay cylindrical structure with a thatched roof. The grain is placed on a clay floor supported by pillars situated in the middle of the dryer.

Fuel is burnt beneath in a firing chamber to generate the heat required for drying. Air is drawn into the structure and, as it is heated, dries the grain, leaving the drier through the thatched roof. However the uptake of this type of dryer by individual farmers has proved slow because the technology is new and the dryer is difficult to install and to use.

10. Some alternatives are in use but there is still a need for low cost dryers which can be constructed locally from available materials. One alternative method uses solar heat and several solar dryers have been developed for drying grain. An indirect solar dryer has been developed by the National Council for Science and Technology in Kenya for women's groups and farmers cooperatives. This is an improvement on other solar dryers in that there is equal drying on all sides so avoiding overdrying. The dryer can be constructed locally and consists of an air collector made of black painted wood covered with sheets of polyethylene and a metal drying chamber. Air is heated in the solar collector and circulated through the drying chamber which contains the grain. Although solar dryers are inexpensive to operate they have the disadvantage of being unable to operate effectively during the rainy season. Mechanical dryers are available but they are unsuited to all but the largest of farmers or where maize can be brought to a central site for drying. They either dry grain in batches, or continuously as the grain flows through. The economics of using mechanical dryers are such that they are best suited to grain marketing boards who buy surplus maize from farmers.

11. Once a crop has been dried to a moisture level which will prevent mould damage and restrict respiration it can be stored. A farmer has to retain a supply of the staple food crop to feed the family and livestock from one harvest to the next. In addition if some of the harvest is intended for sale it may need to be stored until prices reach a suitable level. In storing food crops the farmer has to protect them from rain, theft and, also, from attack by fungi, insects and rodents.

12. The farmer faces problems with cassava storage as it deteriorates rapidly within a few days. Traditional methods include reburial, coating with mud, placing under water or the daily watering of heaps of cassava roots. An improvement on these storage techniques consists of packing freshly harvested roots in boxes containing damp sawdust. This has been reported to store them effectively for 1-2 months. The TDRI has developed a technique in collaboration with the Centro Internacional de Agricultura Tropical (CIAT) whereby cassava roots are treated with a fungicide and stored in polyethylene bags. This has proved to reduce deterioration in trials carried out by CIAT.

13. The basic structures which are used for storing grains throughout Africa are ingenious in their use of local materials and in their construction. Traditional stores are constructed from mud, plant material or stones, or a combination of these materials, often with thatched roofs and they are generally raised off the ground. In the humid areas the structures usually combine drying and storage functions and are more open, such as open-weave baskets and open-sided cribs, to allow more ventilation. As harvests are fairly predictable, the need for storage is limited to, at most, one year. By contrast, in semi-arid areas where harvest are far less reliable, storage granaries are often large, substantial mud structures capable of holding two or more tonnes of grain for periods of up to 5 years. In some areas storage in sealed, underground pits is favoured. Rice is usually stored as paddy in bundles of panicles in sacks or plastic bags. Small quantities of grain are sealed in gourds and clay containers and kept inside the house. Dried grain placed in store is vulnerable to damage caused by insects and rodents. To help combat insect attack the farmer mixes sand, diatomite, limestone or other abrasive minerals with the grain. This traditional method provides an effective physical barrier and affects the insect's cuticle in such a way as to cause subsequent

desiccation of the pest. Similarly mixing selected ashes, herbs or dried animal dung effectively protects stored produce against insect attack.

14. Improved stores have been obtained by making relatively simple modifications to the traditional ones. For example, plastering drying cribs with several layers of mud is used in Zambia and Malawi to render the cribs suitable for maize storage (Fig. 4). The plaster is applied after the maize has dried during the dry season in order to give it better protection during the subsequent wet season when it tends to reabsorb moisture and becomes vulnerable to insect attack. In Kenya, Swaziland and Malawi overhanging metal cones are placed around the legs of the crib, about one metre off the ground. These prevent rats from climbing into the store and so avoid the need for poisons which are potentially dangerous for humans. Instances of new innovations for storage at farm level have been few. Swaziland has a well-developed cottage industry for producing metal tanks for grain storage which have been used successfully by more than 40% of small farmers. Concrete bins developed in Ghana and Zambia were not so successful. Although prototypes were effective they proved too expensive and difficult to construct.

15. Traditional methods of insect control in storage are rarely as effective as the modern synthetic, chemical insecticides and fumigants. Although highly effective, however, these materials can only be recommended when complete safety in use is assured. For example if a storage structure can be made gastight then chemical fumigants, such as phosphine, can be used to control insect infestations. Fumigation is a very efficient method of pest control when properly carried out. Unfortunately it is only in Swaziland, where metal tanks are used for grain storage, that on-farm fumigation is regularly practised. The use of small-scale fumigation on grain stored in farmers' houses cannot be recommended.

16. Insecticides are now widely available in most countries and offer the low-resource farmer a cost-effective means of protecting stored produce. Contact insecticides can be mixed with the grain and sprayed onto the storage containers. Persuading the farmer to use the insecticide and arranging for a supply to be available to him presents a challenge to extension services. Correct application is all important since protection of the grain must be complete otherwise insects resistant to the pesticide will develop and grain losses will occur.

Processing

17. Processed grains and other staple foods make up one of the most important parts of the diet of low-resource farmers. Processing food is almost totally the responsibility of women and, whatever the crop, usually involves several, slow and laborious steps.

18. Sorghum. Traditional milling of sorghum involves soaking the grain to facilitate removal of the bran during grinding. After soaking the grain is pounded in a mortar and the bran winnowed out. A mechanised method known as dry abrasion has been recently introduced into villages in Botswana by the International Development Research Centre (IDRC), the Rural Industries Innovation Centre and the Botswana Agricultural Marketing Board. This improved method consists of a dehuller which separates the bran from the grain without prior soaking and a hammer mill which grinds the grain to meal. Once trained in its use several hours of work are saved. The mills can be constructed from locally available materials. Although expensive several sorghum mills owned by individuals and cooperatives are in operation in Botswana and service milling has also been established. TDRI have developed a semi-wet process using a roller mill for milling sorghum and millets. By the judicious use of tempering water added sufficiently long before milling high yields of fine, high quality flours are produced. This process, however, has yet to be tested in the field.

19. Sorghum grain is usually processed into a porridge or partially fermented flat bread. These traditional foods have a lengthy preparation time and also are not popular with urban populations who prefer rice, wheat or maize products. Sorghum, however, grows well in the semi-arid areas where other crops cannot be cultivated as it is able to withstand drought. New techniques of processing could produce more marketable foods and encourage a wider acceptance of sorghum relieving the dependency on crops such as maize. The low-resource farmer could, therefore, obtain an additional source of income if suitable marketable foods could be developed from sorghum. The TDRI, together with the Kenya Industrial Research and Development Institute (KIRDI), have developed a method of producing 'instant' foods from sorghum. Flours are produced by removing the bran in a pearling machine and then milling the pearled sorghum. The flour is precooked using extrusion technology or drumdrying to produce an 'instant' food (Fig. 5). The pearled sorghum has been packaged and is being promoted as a rice substitute. It is hoped to transfer this technology to other countries where sorghum is the principal cereal crop.

20. Maize. Maize is processed into either flour or porridge. Traditionally shelled grain is milled in a pestle and mortar, sometimes after soaking for a few days so that fermentation can occur, and finally cooked (Fig. 6). The equipment used is inexpensive but the whole process is time consuming and much physical effort is required for the milling and cooking. Various types of hand mills are available but rural women are increasingly making use of community mills. These mills are of three different types, plate, stone and hammer, and use various sources of energy, such as electricity, diesel or waterpower. In areas where fuel or electricity are scarce some plate mills use animal-driven power gear. The choice of mill employed is usually determined by local preferences, scale of production and required output. Hammer mills are commonly used in East

Africa whilst plate mills, which can grind wet grain, are widely used in parts of West Africa. Although many countries import plate and hammer mills an increasing number of countries, such as Tanzania, Malawi and Kenya, have started to manufacture these machines. Stone mills are made in several countries although in many cases the motors for the mills have to be imported. Generally it has been found that hammer mills are the most efficient at fine grading.

21. Rice. Small quantities of rice can be processed for daily use leaving the bulk of the crop stored in an unprocessed form (paddy) in which it is less vulnerable to insect attack. Processing of rice involves several stages including soaking, parboiling, drying, hulling and winnowing.

22. Parboiling is carried out to make hulling easier, as the husk is split during heating, and to reduce the number of broken grains, as the kernel is strengthened during the process. It also lowers loss of B vitamins. Traditionally parboiling consists of heating the soaked grain in a metal container over a fire until the surface grain shows signs of splitting. The grain is then drained and sun dried. An unpleasant odour is regularly associated with rice parboiled in this way and remains detectable through to the cooked stage. This is due to the development of fungi which produce mycotoxins together with fermentation caused by prolonged soaking or delayed drying. The TDRI has developed a processing technique in which the quality of rice is improved and the off-odour does not develop. This method uses a modified container into which a mesh platform supported on metal rods is inserted. Water under the platform is boiled to provide steam for parboiling the grain placed above the platform. The grain is steamed, soaked for a day and then steamed again. This technique gives a final product with no detectable off-odour. In the Philippines the International Rice Research Institute (IRRI) is investigating a method of 'dry' parboiling in which the wet paddy is simultaneously parboiled and dried by being mixed with sand at 200°C.

23. Hulling is usually done by pounding the grain in a mortar. This produces an undermilled rice with a high bran content which gives it a high nutritional value. It does result, however, in a large number of broken grains. Most of the available mechanised devices are too expensive for the individual farmer and are usually found in commercial enterprises or village cooperatives. Of the hand-operated hullers the Engelberg-type is the most commonly used. It consists of a longitudinally ridged steel cylinder which rotates against a fixed horizontal knife blade. This device tends to overmill and consequently removes a large amount of bran with the husk. Other hullers are of two basic types, under- runner disc and rubber-roller. The latter have proved to be the more efficient but have certain disadvantages such as the deterioration of the rollers due to high temperatures and humidity and the high cost of replacing them. Where commercial power-operated mills are available they are being used increasingly by rural women.

24. The traditional method of winnowing is to toss the rice kernels and separated husks into the air from a flat wooden tray. As the kernels are heavier they fall back on to the tray first while the husks fall to the ground. Pounding and winnowing are usually carried out alternatively until the rice is fully hulled. Hand and pedal-operated winnowers of various types are available and give an improved output compared with the traditional method (Fig. 7). One such hand-operated device consists of a vertical drum with a fan at one end. The fan is operated by turning a handle bar and as the bar rotates the husks are blown away from the side of the drum while the grains drop to the bottom. This winnower is inexpensive and easy to manufacture. Commercial machines are available to separate the husks and are often incorporated into the huller.

25. Legumes. Processing legumes involves a number of steps including hulling, grinding and cooking. The traditional method of hulling is to

soak the legumes or mix them with oil, sun dry them and pound them in a pestle and mortar. The husks are then winnowed off.

26. Small, hand/power-operated hullers are available. These are under-run disc shellers, blunt-plate mills or roller mills. None of these, however, is totally satisfactory as they all cause splitting of the cotyledon and loss of the embryo. Improved techniques are presently being developed in India. These involve the use of heat to loosen the husk followed by tempering. The husks are removed by abrasion in a pearling machine. These techniques are very efficient but are only suitable for large-scale commercial operations.

27. Grinding is usually done in a mortar, stone grinders or in plate or hammer mills. Legumes are traditionally cooked for 1-4 hours after overnight soaking and results in the loss of valuable nutrients and solids. To avoid these losses precooked, quick preparation legumes have been developed. These use flaked split, pressure cooked and dehydrated legumes. They require careful control to ensure quality and are only feasible where centralised storage and processing facilities exist.

28. Groundnuts are an important cash crop for the low-resource farmer. Unlike other legumes they do not have a hard husk and are only loosely enclosed in a pod that is easily broken. There is an economic incentive for the farmer to improve his output and simple equipment to do this has been developed. A wooden, hand-operated decorticator, developed by UNICEF in Kenya, is claimed to be three times more efficient than traditional hand decorticating. This machine, which can be easily constructed locally, consists of a semicylindrical trough in the centre of which is fitted a vertical paddle (Fig. 8). This can be moved backwards and forwards. As it does so it presses the groundnuts against a wire screen which removes the husk and allows the kernels to fall through into a box underneath. Simple, hand-operated equipment, used in Senegal, washes groundnuts by agitating in a trough of water, whilst a 'Senegal' screen is used for grading.

29. Cassava. This staple is processed into a variety of dried products according to local traditions and needs. The main products are chips, flour and gari. Gari is becoming increasingly popular in certain countries of West Africa, such as Ghana, because of a shortage of other food items. Processing cassava is one of the most time consuming and strenuous tasks of African women with the traditional process taking several days to complete. In addition, various stages, such as sun drying, are unhygienic whilst grating frequently causes lacerations of the fingers.

30. Cassava has to be soaked for a few days before processing to reduce the cyanide content of the roots. It is important that any modification to the traditional processing methods should result in a comparable cyanide reduction. Depending on the final product the stages in the treatment of cassava are slightly different. The first step in all cases is peeling the root by knife or cutlass. There have been attempts to improve on this method but as the roots occur in different shapes and sizes the design of an appropriate peeler has proved difficult. Peelers which have been tried resulted in a large degree of wastage compared to hand peeling.

31. To make chips and flour, the cassava root is chopped into small pieces and sun dried. Chips are produced after drying for 3-10 days depending on the weather. Solar dryers may be able to accelerate this process. The chips are pounded in a mortar to make flour. Plate or hammer mills, similar to those for milling maize, could be used to produce flour on a collective basis.

32. Gari preparation is a lengthy process but, once prepared, it is easy to cook and a well-dried product will keep for several months if necessary. In the traditional process the peeled root is washed and grated by rubbing against a perforated metal pan. A few hand/pedal-operated and mechanised graters are available. One such pedal-operated device, developed by the Intermediate Technology Development Group (ITDG) and used in

Nigeria, can be easily constructed from locally available materials and bicycle scrap. It consists of a vertical disc which is rotated by pedalling. Grating slits are cut into the disc and cassava roots are fed in through a hopper. Mechanised graters have been designed and developed in Sierra Leone, Liberia and Ghana. All these graters have a considerably increased output compared with hand grating.

33. The grated cassava is allowed to ferment spontaneously. Simultaneously water is extracted by placing the mixture in bags or metal containers onto which heavy weights are placed for 2-5 days or, alternatively, pressure is exerted by sticks placed on both sides of the bag and tied together by ropes. A development of the traditional method has been designed in Sierra Leone. It is a press consisting of two wooden or metal frames held together by hand screws and threads in such a way as to exert pressure on the sack of fermented cassava held between them. The effort required to set up this system is considerably less than that needed for the traditional method. A screw press has been developed and is being tested, while a hydraulic press, developed in Ghana, is available but expensive to buy.

34. After fermentation the cassava mixture is sieved in metal or rafia sieves. Hand/power-operated sieves, developed in Ghana, are available. Sieving is followed by roasting which causes gelatinisation of the mixture. The traditional method of roasting cassava is in metal pans over a fire. An improvement on this, developed in Ghana, is to roast the cassava in a sheet metal tray placed on a brick-walled stove. This is fueled with firewood and has a chimney to reduce smoke. The main disadvantage of this technique is the frequent rebuilding of the walls which are affected by the heat. It is, however, simply designed and can be constructed locally.

35. Oil seeds. Vegetable oils are an important commodity and are often in short supply. Palm oil, in particular, provides a major source of income

for rural women in the humid areas. Whilst most is used for cooking, some is used in soap making.

36. Palm fruits are harvested by men but the oil processing is the women's responsibility. Once harvested the fruits are removed from the bunch by hand or axes and cutlasses. An improved method of removing fruits is the use of a hand-operated device. Once such device, used in Cameroon, consists of a metal drum inside which is a number of iron rods supported by discs at both ends. When a handle is rotated the palm fruits are removed from the cob by the action of the rods. This is a safer method than the traditional axe or cutlass.

37. The fruits are boiled for 5-10 hours in a traditional iron pot over a fire. Sterilisers, in which the fruit is sterilised by steam produced in a boiler, have been constructed in most palm-oil producing countries and these are able to deal with a much larger quantity of fruit in a shorter period of time in comparison with the traditional pot.

38. The oily fibres are separated from the exocarp by either pounding in a mortar or trampling in a pit. These methods are slow and laborious and a palm pounding machine has been developed to give a much faster operation. In the traditional method water is added during fibre separation and the oil is scooped and sieved from the mixture of fibres, kernels and water. Afterwards the oil is boiled in drums and then left to cool. The vegetable debris sinks while the oil is scooped off the surface. Several types of screw and hydraulic presses have been developed to make this final stage of oil extraction easier and less time consuming. One such press is a continuous oil screw press, known as an expeller, which is in use in Ghana and other countries. This consists of a seed feeder, a pressing box, a cage which surrounds the shaft and an adjustable cone. The horizontal shaft rotates and its screw action and internal pressure pushes the boiled palm fruit forwards. The oil is extracted and flows out through perfora-

tions in the box while the cake is forced out through the opening around the cone.

39. Oil can be extracted from several other seeds. Coconut oil is important in many coastal areas of Africa and, like palm oil, has many stages in its production but several devices have improved the operation. For example, grating the shelled coconut is usually done with a perforated metal grater with the risk of lacerations to the fingers. Several types of hand-held or hand/power-operated graters have been developed and are safer to use and give increased output compared with the traditional method. Most of these are inexpensive and easy to manufacture. Similar presses to those used for palm oil production can be used for coconut oil.

40. Until recently farmers in Zambia had no small-scale means of extracting the oil from their sunflower crop. They were forced to market the raw product and then buy the vegetable oil once it had been processed in large oil mills elsewhere. The TDRI has developed a small-scale expeller for sunflower seeds and several have been introduced into cooperatives in Zambia. In addition, it has been successfully used for coconut and groundnut. The expeller has proved to be efficient and it is hoped to spread its use to other countries.

41. Technologies have been developed for other oil seeds which are of more localised importance. For example, shea nuts, which are processed into shea butter, an edible fat which provides an income for rural women. The traditional method of producing the butter was lengthy and only produced about 25% fat. The German Appropriate Technology Exchange (GATE) developed a hand press which squeezes fat out of shea nut powder at high pressure. The press is particularly attractive because it does not use water and reduces the requirement for fuel, in addition to reducing the amount of time spent in producing the butter. Although expensive to purchase initially, it is estimated to pay for itself within 2 years because

of the extra income it generates. About 20 of these presses are in operation in Mali at present.

Fisheries

42. Marine and inland fisheries are important as a source of food and employment in many African countries. Fish provides protein, vitamins and essential minerals and is a cheap and valuable supplement to the basic diet of poor and undernourished populations. Fishing communities can often increase their income by supplying fish to inland communities. Major coastal fisheries are found in West Africa, Mozambique and Tanzania and inland fisheries around Lakes Chad, Victoria and Malawi. Another important fishing area is the inland delta of the River Niger in Mali where the seasonal flooding of the river supports a large population of migrant fishermen.

43. Although it has to compete with large industrial fleets the artisanal fishing sector of West Africa catches 75% of the total regional catch of 0.9-1.35 million tonnes a year. The artisanal fisheries are small, poor and dispersed but are well organised and efficient with a sophisticated and complex marketing system. Woman play a dominant role in the fishing communities being responsible for buying, processing and marketing. Many own boats and gear and they may also provide a source of credit to the fisherman to buy boats and equipment.

44. Fish is a highly perishable commodity and heavy losses occur at every stage of the post-harvest chain. Losses occur during handling on board and after landing, from blowflies during drying and beetles during storage, and during smoking, packaging and transport due to crumbling and spoilage. Much of the artisanally caught fish is sold immediately on landing but the major proportion is dried and otherwise preserved, especially where it is to be transported over long distances. In the case of migrant fisherman of Mali 3-4 months usually elapse between catching and ultimate consumption.

Losses of up to 50% of processed fish have been reported from Lake Chad because transporting fish from this remote area to market necessitates long periods of storage.

45. The commonly used methods of fish processing are drying, salting and smoke drying. The traditional and most widely used means of drying is to simply to spread the fish on straw or the beach or on mats if available and leave them to dry in the sun. Severe losses result from attack by blowflies, particularly during the wet season when drying is slow. An improvement on this method of drying is the use of simple racks which raise the fish off the ground and improve the airflow around the fish. These racks are constructed from local materials and are cheap and effective. In Senegal in 1984 33% of the catch was lost through infestation in the wet season by blowflies. The TDRI has demonstrated in Malawi and the Gambia that dipping wet fish in the insecticide, pirimiphos-methyl, completely controlled blowflies without creating any health risks for the consumer. This technique has potential for reducing fish losses in many other countries.

46. Solar driers consist of a flat wood or mud box covered with a double sheet of glass or polyethylene. The inside of the box is painted black and this surface absorbs solar heat so the temperature inside is considerably higher than ambient. Cold air enters through holes in the bottom, becomes hotter and rises and flows out through vents in the top. The fish is dried in this airflow. Similarly, solar tents made from clear and black polyethylene sheets on a wooden framework have been tested in the Gambia as well as Bangladesh and West Africa (Fig. 9). As well as drying fish the elevated temperatures and restricted access (provided the air inlets are screened against flies) reduce insect attack.

47. Salting not only helps dry the fish but also prevents microbiological spoilage and extends the shelf life. It is usually carried out by sprink-

ling dry salt between stacked layers of split fish or immersing in brine. The major advantage is that it is believed to reduce blowfly and beetle attack, and it reduces the growth of certain pathogenic bacteria.

48. Smoke drying is widely used in West Africa. Whilst it is primarily used to dry fish, the heat reduces blowfly attack. Phenolic compounds, which inhibit bacterial action, may be deposited on the surface of the fish. Smoke drying is traditionally carried out over a grid or fire or in ovens made of mud, wood or oil drums (Fig. 10). While these are cheap and easy to construct their capacity is small. They also require large quantities of firewood which is becoming a scarce and costly commodity in many parts of Africa. Many different improved ovens with a more efficient use of fuel are slowly being introduced. One such oven is the Chorker fish smoker which was introduced into Ghana by the Food and Agriculture Organization of the United Nations (FAO) and promoted by the UNICEF and the United Nations Development Fund for Women (UNIFEM). This smoker has a larger capacity than the traditional ovens and consists of 10-15 stacked trays encased in a flexible and resistant sheeting through which heat and smoke constantly circulate from the oven. It is easy to operate, reduces smoking time and is inexpensive to construct although the design requires skilled workers for its construction. This oven was quickly accepted in the Ghanaian villages into which it was introduced, but it has only been taken up on a limited scale in Ghana and other West African countries. The FAO is continuing to develop the Chorker oven in Ghana and is testing new construction materials.

49. When smoking is completed the fish are packed into tight bundles using straw mats, wicker baskets, hessian sacks or wooden boxes. In Mali the straw mats used for packaging are treated with the insecticide malathion and one study showed that fish losses decreased from 42% to 9%.

Fuel/energy

50. At present one of the most important needs of the low-resource farmer is an alternative source of energy as the traditional fuel, firewood, is rapidly diminishing. In the long term this can be rectified by replenishing the source through the creation of village wood lots and planting quick growing trees. In 1977 the Kenyan National Council of Women initiated a Green Belt Movement. This is a country-wide tree planting programme carried out by women's groups. Tree nurseries are established and women rear seedlings to sell back to the National Council of Women for distribution to other groups and rural communities around the country. Apart from increasing the supply of firewood in rural areas other benefits from the programme include soil conservation and land reclamation together with additional income from the sale of seedlings.

51. A more immediate answer to the energy problem is the increased use of briquetting. This is an effective way of utilising crop residues. Cellulosic residues, such as rice husks, groundnut shells and coir dust, can be made into briquettes and become an efficient fuel. In rural areas where residues are plentiful briquette production can provide employment and income. So far, however, small-scale production methods have not been particularly successful. Briquetting equipment is usually designed for use in developed countries and requires a trained workforce with the requisite technical knowledge as well as a source of spare parts. The supply of crop residues is often irregular depending on harvests. Organisations such as the TDRI and the ITDG are investigating improved methods of small-scale briquetting in order to exploit the full potential of crop residues. Hand-briquetting is known in India whereby a Cinva ram, a simple device which is usually used for compacting earth in the manufacture of building blocks, is used to compress materials such as grass, grain straw and sugarcane leaves into fuel bricks. These bricks are not as tightly packed

as briquettes but burn well. The ram has been in existence for many years and is simple to operate. It is made of cast iron and can be made locally. To be profitable the ram should be owned by village cooperatives rather than individuals.

52. An alternative to briquetting is gasification. The TDRI favour carbonisation prior to gasification and has developed a charcoal-fuelled gasifier system which provides energy for the operation of corn mills and rice hullers as well as water pumps for small irrigation schemes.

53. Solar energy has not yet been fully exploited and will be used increasingly in the future although its use is likely to be limited. Solar cookers have not proved very successful. This is partly because of the conflict with the local custom of cooking in the evening after the sun has gone down, and partly, because of this requirement for direct sunlight, they have to be constantly adjusted as the sun moves. Solar driers although not used yet on a large scale are more efficient. At present they do not operate to their full potential and the TDRI is investigating methods to make them more effective by improving the efficiency of the collector.

54. More efficient energy sources would be invaluable for many post-harvest operations. For example, in the fishing communities energy is a continual requirement not only for the fishing fleet but for processing and transport. It is surprising that the use of the improved ovens with their efficient use of fuel have not been accepted on a much wider scale. This almost certainly results from a failure to involve the community in the design stage, leading to socially unacceptable solutions.

APPLICATION OF INTEGRATED PRINCIPLES AND CONCEPTS FOR MANAGING RESOURCES FOR LOW-RESOURCE AGRICULTURE TO POST-HARVEST TECHNOLOGY

55. In the past most development programmes, whether national or international, with few exceptions, were aimed at men. Agricultural programmes concerned themselves only with the needs of male farmers. With the realisation that Africa has to increase food production in order to feed its rapidly increasing populations attention is moving from cash crops to food crop production. African women grow most of the continent's food and about 75% of all farming is done by women. Donor agencies and national governments are gradually recognising the importance of women in African agriculture and beginning to realise that increased rural development will not be achieved if the technology proposed does not fit with the lifestyle imposed on women by their many duties.

56. In addition to growing crops and providing fuel and water women are almost totally responsible for harvesting, storing and processing food crops. All these activities involve much time and hard, monotonous work so any new technologies that can be shown to reduce time and effort will be welcomed. In addition to increasing production women would have more opportunity for developing activities that supply additional income, such as handicrafts, textiles or beekeeping.

57. No single machine or new practice will drastically improve the post-harvest operations of the African farmer but a large number of simple technologies do exist to improve the various stages of post-harvest treatment of crops. Organisations such as the ITDG and VITA have introduced suitable intermediate technologies to rural communities in many African countries with the emphasis on low-cost improvements and innovations.

58. Before introducing new technologies international and national organisations have to carry out background studies to determine which types of

technology are necessary and appropriate for existing conditions. Social, cultural, political and economic factors must all be considered. The traditional practices will not be abandoned until the improved technology has clearly been shown to be an effective improvement and has no consequent disadvantages following its adoption. The traditional practices have evolved over a long period of time and are adapted to local conditions and skills, the needs of the farmers and to established social customs. This is why technologies based on traditional practices, such as the Chorker ovens or the storage structures for cereals, have proved successful where originally introduced. Data from background studies, and subsequent follow-up studies, are also necessary for donor agencies committing funds and personnel to particular projects.

59. When the new technology reaches the village it may not always be relevant or accessible to women. Most extension workers are male and they communicate usually with the men of the village. Women may be completely unaware of the existence of improved technologies and are rarely involved in the initiation of new technologies. They are usually too over burdened with work to be innovative in developing technology themselves. It has been found that if powered machines are introduced the men take over even if it concerns work traditionally done by women which results in women losing their livelihood. Men have a readier access to credit and the time to specialise in a single activity. Commercial palm oil extraction, for example, is increasingly becoming dominated by men. More women involved in training and extension work are required to inform women about available technologies as well as how to operate and maintain them. They will be sympathetic to the requirements and commitments of women and be able to adapt training courses to make them particularly appropriate. The important concept of working in groups can be introduced by extension workers.

what needs to be done	how to do it	who should do it	what limits it
Principle A: Components of low-resource agriculture			
develop improved technology based on social, ecological economic and political considerations in the local conditions	field surveys communication with farmers	farmers, NGOs, national research centres, extension workers, IARCs	lack of information on all relevant factors
	field trials of new technology	IARCs, NGOs, national research centres	
Principle B: Links between agricultural systems and other bodies			
obtain help of village elders	discuss problems with elders	extension workers, IARCs	lack of time and resources
obtain accurate information on structure and organisational practices of national governments, and NGOs if relevant	consult extensively with national officials and arrange donor coordination	national government officers, IARCs, NGOs	possible conservatism
scrupulously follow national politics and administrative chain-of-command		IARCs	nature of national politics
Principle C: Responses to uncertain conditions			
adapting and improving local technology and practices rather than replacing them	field surveys to obtain information on local technology and what is required by farmer communication with farmers	IARCs, NGOs, national research centres	lack of sufficient time and personnel
encourage and exploit local knowledge and ideas wherever possible	ensure farmers' participation	IARCs, NGOs, national research centres, extension workers	communication difficulties, lack of time and resources
Principle D: Local resources			
accumulate knowledge of, and reasons for, traditional techniques	field surveys farmer participation literature searches	IARCs, NGOs, national research centres and universities	logistical difficulties inherent in carrying out field work in developing countries language difficulties formulation of suitable questionnaires difficulty in obtaining obscure publications

what needs to be done	how to do it	who should do it	what limits it
Principle E: Agriculturalists as heterogenous group			
ensure technology appropriate for relevant user group; this includes factors such as cultural acceptability, ease of comprehension, efficacy in local conditions and availability of appropriate resource base	adequate sociological background studies demonstrate value of technology	IARCs, NGOs, national research centres	lack of funds and personnel
	thorough training in construction, operation and maintenance including written material if appropriate	NGOs, national research centres, extension workers	difficulties in usage, illiteracy lack of trained personnel non-availability of raw materials
	adequate market surveys of availability and costs of raw materials	farmers, NGOs, extension workers, national research centres, IARCs	lack of reliable data, deliberate misreporting (e.g. smuggling, fear of duties and taxes etc.)
Principle F: Role of women			
establish women's role	sociological surveys	IARCs, NGOs, national research centres	
ensure technology adapted to women's role	ensure background studies mentioned in E give full weight to women's roles		
ensure information on new technology disseminated to women	research and extension workers should ensure women help to devise and are aware of, and trained in, use of improved technology		male-dominated institutions possible restrictions on women imposed by male presence in rural communities communication difficulties among rural communities
increase role of women in agricultural training and extension	increase training of women		limited numbers of women in research and extension
Principle G: Agricultural systems sustainability			
ensure technology appropriate to farmer	adequate long-term field trials follow-up surveys to determine effectiveness, subsequent modifications if necessary training if necessary	IARCs, NGOs, national research centres	difficulties of adequate testing under local conditions for extended period
ensure robustness of system through durable construction material and general flexibility of techniques			
full training in new technology especially where potential problems, e.g. use of pesticides		NGOs, national research centres, extension workers	lack of personnel and resources
ensure continuity of usage			

what needs to be done	how to do it	who should do it	what limits it
ensure inputs are available (when and where needed) at an affordable cost as a principal component of project	include in project objectives	funding agencies, IARCs	reluctance to hold stocks, deterioration of stocks, customs and bureaucratic delays, currency problems, theft/misappropriation
Principle H: Local participation			
training in improved technology, especially for women	increase training facilities increase numbers of women involved in extension and training	national centres, extension workers	lack of resources
training of local teachers able to communicate in ethnic languages	train locals to undertake own extension work through workshops, cooperatives etc., integrate feedback from groups in subsequent operations	national centres, extension workers	relocation of official teachers out of area, ethnic differences between official teacher and community

Access to credit facilities is often denied to individual women but is more readily available to a group or cooperative. The most successful cooperatives are those initiated by the women themselves or those in which women are allowed to influence the direction leading to full control.

60. Farmers generally are responsive to new ideas provided the innovations are shown to be effective and profitable. In many cases it has been found that information on successful improvements is not disseminated to other regions or countries. The Chorker ovens, for example, have proved very effective and have been accepted in the Ghanian villages into which they were introduced but they have not been adopted on a wide scale. Many organisations believe the project is completed once the technology is accepted at the targeted locality and little attempt is made to further its promotion and acceptability. Information on successful and appropriate innovations should be disseminated on as wide a scale as possible and

publicity, advertising and field demonstrations should be arranged by international and national organisations together with local extension workers.

POTENTIAL OF POST-HARVEST TECHNOLOGY FOR SUPPORTING DEVELOPMENT OF LOW-RESOURCE AGRICULTURE

61. Despite the introduction of many improved technologies there is still scope for much improvement in all post-harvest operations to make them less laborious and time consuming as well as more efficient. However, technical innovations in themselves are rarely sufficient. Devices or processes can be developed and continually refined until their potential is fully realised but if this is done in isolation from other production stages in the end their effectiveness in the post-harvest chain may be negated.

62. The fishing communities illustrate this point. As the capacity for fish processing is increased by improved ovens then a larger quantity of fish has to be supplied regularly to make the ovens economic. Therefore, Improved fish catches are required for the processors and so corresponding improvements are needed in fishing boats, nets and gear. Fishing could be made more efficient by fitting engines to the traditional boats. The disadvantages of this are that standard engines are often not suitable because of their high fuel consumption and the necessity of regular maintenance. Better landing and handling facilities are required together with increased provision for holding fish during seasonal gluts. Alternatives to the currently used insecticides are needed and better methods of application investigated. Modern packaging technology could reduce some of the losses of preserved fish which occur through physical damage during transportation and through insect infestation. In West Africa, however,

the present system works well and so all innovations should aim to improve and strengthen this, rather than try to replace it.

63. Aquaculture schemes have been initiated in some countries to help the fishing communities by providing a constant supply of fish to offset seasonal fluctuations. For example, the United States Agency for International Development (USAID) funded such a scheme in Mali where Tilapia were introduced. At present donors and government are generally reluctant to invest in these projects which are thus hampered by insufficient funding. This reluctance is because agriculture has first priority on available water but also because little advance has been made in the development of breeding techniques and fast-growing species.

64. As far as storage is concerned the traditional farming system and the storage structure are compatible and have proved to be satisfactory with the level of losses well contained. This is the case only, however, if a farmer continues to grow the traditional varieties. Once a farmer changes to the new improved varieties of grain, which is happening increasingly, then changes in the traditional storage practice are required. The traditional varieties were selected over many years for their ability to withstand long storage periods. These new varieties are bred to give increased yields but have poorer storage attributes such as increased susceptibility to attack from storage fungi and insect pests. In the long term crop varieties can be bred specifically to be more resistant to storage pests but this will take several years.

65. It is now particularly important that pest control measures are improved in order to combat the major pest of stored grain, Prostephanus truncatus, the larger grain borer. This pest tends to strike at the low-resource farmer who stores his own grain and cassava and who is least able to combat it. Until 1980 it was known only in Central America but was then found in Tanzania. It has now spread to Kenya and other East African

countries and has also been reported in Togo. Losses of about 10% of stored grains have been reported which are considerably higher than those experienced before the arrival of this pest. Investigations by TDRI showed that the pest develops better on cobs than on shelled maize and initially farmers were recommended to shell maize before storing. Later it was shown that infestations could be controlled by mixing permethrin dust with shelled maize before storing it in sacks. Much work is still required to bring this major threat to farmers' food stores under control.

66. There is now an urgent need for more awareness of the consequences of introduced changes and for attention to be given to ensuring that the farmer can continue to conserve grain using an appropriate post-harvest technology. The well-being and livelihood of Africa's farmers depends on this ability.

67. Many simple, inexpensive devices have successfully alleviated some of the drudgery involved in processing food crops. More are still required as the various stages in the processing chain would benefit from efficient and appropriate technologies. In the past projects have failed, however, because, whilst improved processing resulted in a greater output, markets for the sale of these surpluses were not exploited. Much greater emphasis should be given to marketing in the post-harvest chain than has been done so previously.

68. Where new technologies are introduced they should be backed up with advisory services and technical support should be provided. Follow up studies are vital to ensure that the introduced technology remains viable.

69. It is not only in post-harvest operations, however, that improved technology is still required. Improvements are needed in practically every other area of daily life of the low-resource farmer. These improvements are rarely independent of each other and often are only part of much greater necessities. For example, ice is the simplest means of preserving

fish onboard ship as well as onshore but generally it is not used in the small fishing communities. Its production would require major inputs such as water and electricity as well as capital for installation and maintenance of the plant, and often some or all of these are not available. (Despite these problems, however, the use of ice is increasing, for example, in the artisanal sector in Senegal.)

70. Development agencies should aim for an integrated and multidisciplinary approach in their programmes wherever possible. A European Economic Community (EC) project in Gabon provides an excellent example of this integrated approach. It was traditional in villages in Gabon for men to clear the forest area enabling women to plant a succession of crops. The soil rapidly became exhausted and, as a result young adults migrated to the urban areas in search of a livelihood. The EC project promoted the cultivation of plantains, the most important staple carbohydrate in Gabon. It supplied the rural community with a clean water supply, school, dispensary, 80 kilometres of feeder road to the river and a reliable barge service which called at a fixed time on a known day. Village life was considerably improved. Plantain production and collection provided employment and so the young adults returned. The road and barge enabled the reliable and regular transport of plantains which were assured of a steady market in the major oil port.

71. Potentially there is scope for further improvement in post-harvest technology, either by itself, or within a larger, integrated development programme and this improved technology will make a significant contribution to the quality of life of the low-resource farmer.

GLOSSARY

CIAT	Centro Internacional de Agricultura Tropical (Colombia)
EC	European Economic Community (Belgium)
FAO	Food and Agriculture Organization of the United Nations (Italy)
GATE	German Appropriate Technology Exchange (Germany)
IDRC	International Development Research Centre (Canada)
IRRI	International Rice Research Institute (Philippines)
ITDG	Intermediate Technology Development Group (UK)
KIRDI	Kenya Industrial Research and Development Institute (Kenya)
TDRI	Tropical Development and Research Institute (UK)
UNICEF	United Nations International Children's Emergency Fund (USA)
UNIFEM	United Nations Development Fund for Women (USA)
USAID	United States Agency for International Development (USA)
VITA	Volunteers in Technical Assistance (USA)

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FIGURE CAPTIONS

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Fig. 3. Maize cobs drying inside a traditional crib (TDRI).

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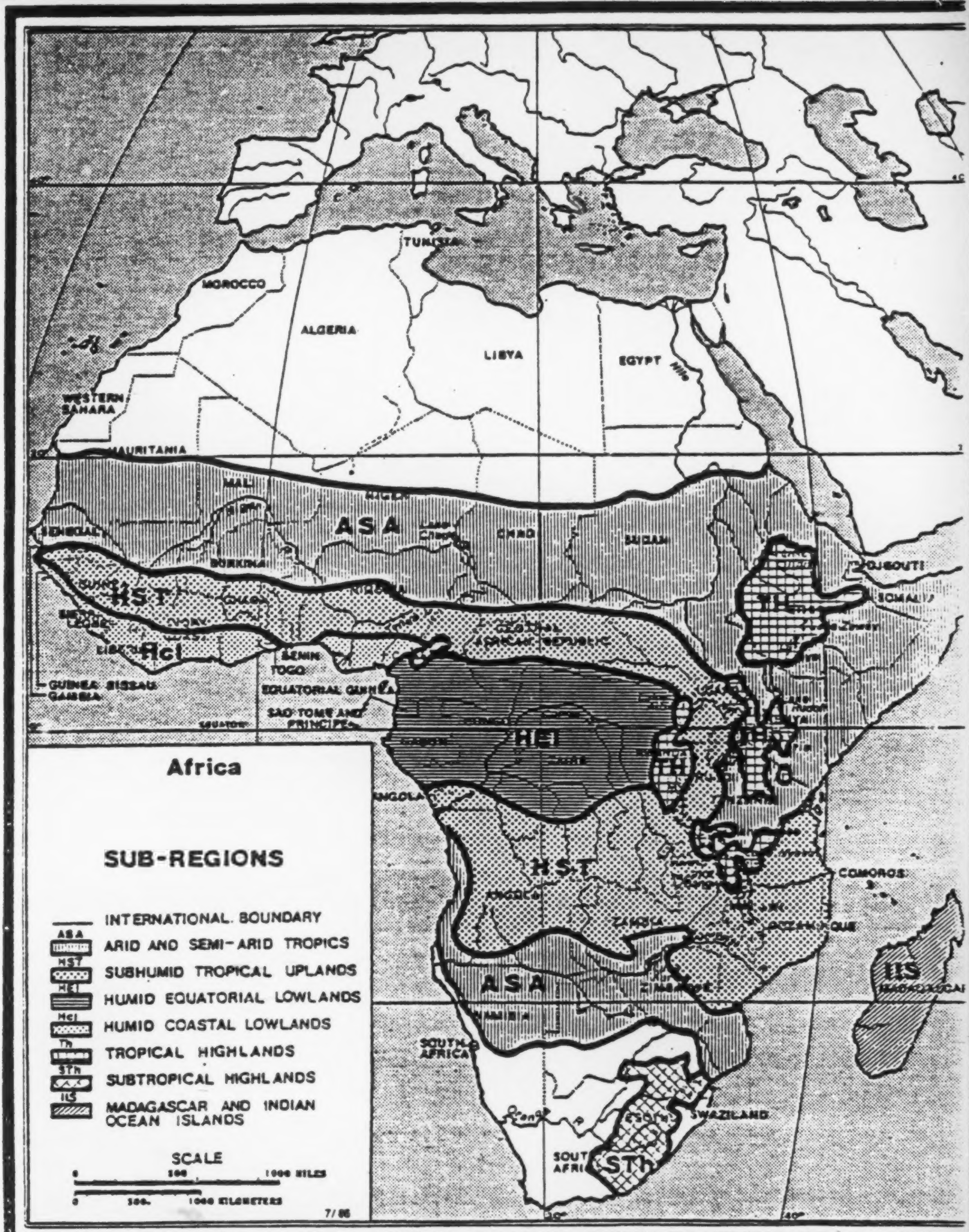
Fig. 10. Traditional fish smoking pit at Lake Malawi.


Africa
SUB-REGIONS
INTERNATIONAL BOUNDARY
ASA ARID AND SEMI-ARID TROPICS
HST SUBHUMID TROPICAL UPLANDS
HEl HUMID EQUATORIAL LOWLANDS
Hcl HUMID COASTAL LOWLANDS
Th TROPICAL HIGHLANDS
STh SUBTROPICAL HIGHLANDS
IIS MADAGASCAR AND INDIAN OCEAN ISLANDS
SCALE
0 500 1000 MILES
0 500 1000 KILOMETERS
7/86
MOROCCO
ALGERIA
TUNISIA
LIBYA
EGYPT
WESTERN SAHARA
MAURITANIA
MALI
NIGER
SENEGAL
ASA
CHAD
SUDAN
DJIBOUTI
SOMALIA
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NIGERIA
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CENTRAL AFRICAN REPUBLIC
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GAMBIA
EQUATORIAL GUINEA
SAO TOME AND PRINCIPE
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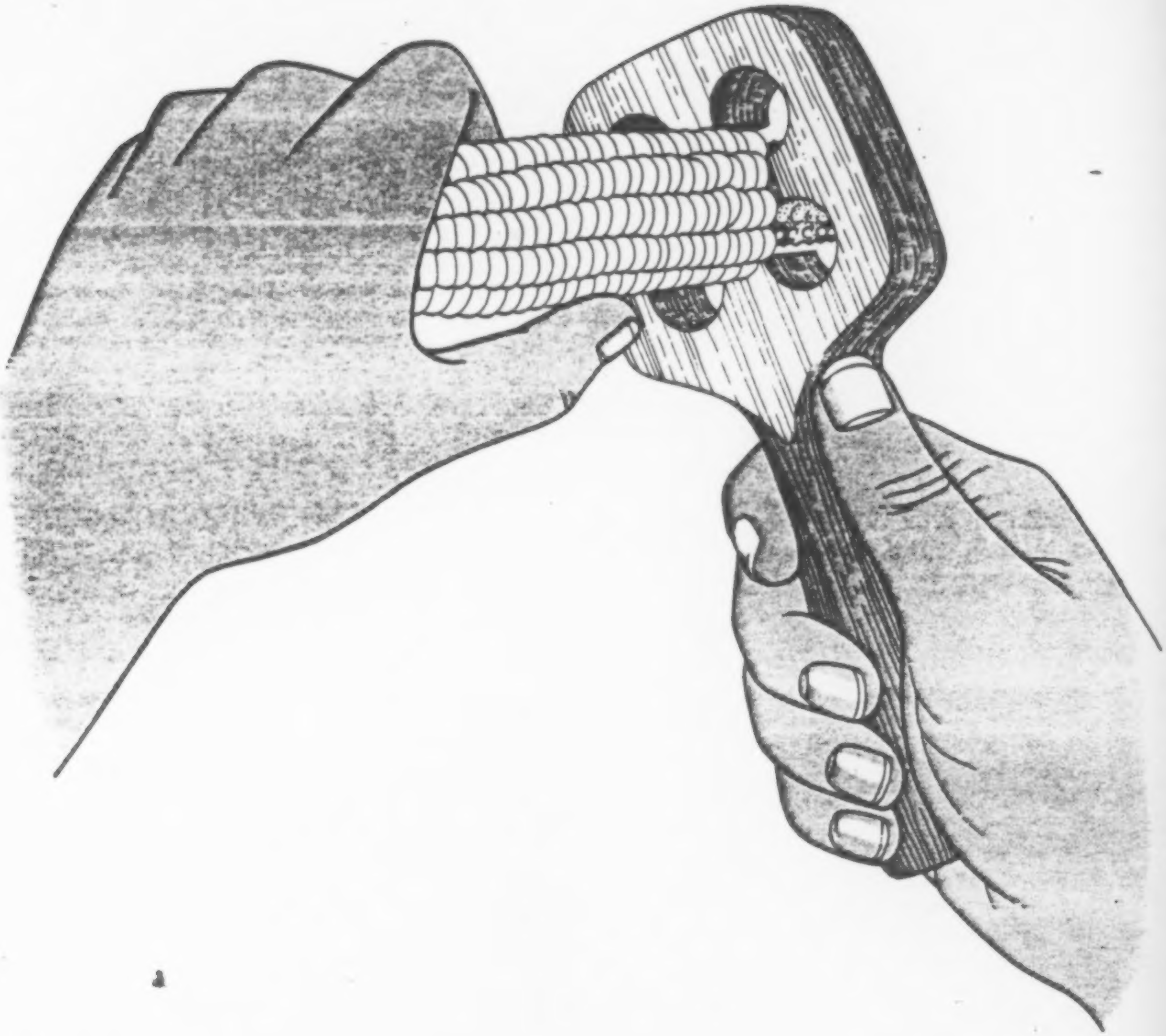

REVISED DRAFT

LOW-RESOURCE AGRICULTURE IN AFRICA

OTA TECHNOLOGY PAPER SERIES
Communication and Information Technologies

by

Frances B. Hays
Academy for Educational Development, Inc.

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REVISED DRAFT

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APPENDIX A

Figure 2: Communications Equipment, Facilities, and Training in African Countries

APPENDIX E

Figure 3: International/Regional Institutions in African Countries
Figure 4: African-Based Information Centers

SECTION I
ABSTRACT

1.1 The Independent Commission for Worldwide Telecommunication Development (the Maitland Commission) entitled its recent report The Missing Link. A conference this year on telecommunications for development was called "Bridging the Gap." Despite ongoing studies, recommendations, and pilot projects, **three gaps appear to be widening in communication development:**

- Between Africa and the rest of the world;
- Between African nations that have strong infrastructures and those that do not, and
- Within African nations, between urban and rural areas.

1.2 **Communication is still the missing link.** Without communication, information does not flow. Isolation flourishes. Development does not proceed. Education and commerce come to a halt.

1.3 Technologies do exist to bridge the gaps, but technical solutions alone are not sufficient. Overriding the technological considerations are human and institutional conditions. African leaders and planners must fit the new technologies to local institutions and personnel. **Fundamental to the outcome of the technology transfer process is the commitment of African leaders to rural development.**

1.4 This report examines the applications of three communication and information technologies to low-resource agriculture. These technologies are **broadcast radio and television, satellite-based telecommunications, and microcomputers.** Increasingly these technologies are becoming inter-related. Satellites can be used to transmit broadcasting, telephony (voice, text, and graphic information that passes over telephone lines), and microcomputer services. Thus, satellite delivery can either replace or extend the range of land-based transmission systems.

1.5 Of the technologies under consideration, **radio** has the longest history as a communication tool in development and the most specific applications in agriculture. Its success has been proven in project contexts, and its relatively low costs and wide reach make it the easiest of the technologies to use for development purposes now. **Television** was used for massive educational programs in Africa, but eventually equipment and production costs precluded its regular use in development. Everywhere in the developing

world introduction of **telephone** services has shown their utility as a development tool, in particular for the growth of commerce and business. **Satellite transmission** would enable African nations to bring telephone services to rural populations in the near future without having to wait the long time needed to extend land-based cable or microwave systems. **Microcomputers** are the newest of the communication/information technologies discussed here to enter Africa. Their ability to handle information is potentially revolutionary in situations where rapid access to information is needed. In agriculture, the largest and most immediate impact of microcomputers may be on marketing.

1.6 Early applications of communication/information technology to agriculture were developed first in Asia and Latin America. Leesons from projects there are now available and ready for adaptation in Africa. In the case of satellite-based telecommunications, the first applications were in health and education and only later in agriculture. Microcomputers were introduced first in government and business administration; agricultural applications have been developed more slowly. In the developing world, most uses of microcomputers occur in the more mature agricultural settings of Asia; applications in Africa are still rare.

1.7 **While these technologies offer potential benefits to the rural populations of Africa, issues of human resource development and management must be faced on both the national and institutional levels.** National policies can inhibit or encourage technology use and adaptation. Not only must Africans learn new technological systems, they must also design, test, and establish applications of value to rural areas. The needs of agricultural institutions - ministries, extension services, cooperatives, research centers, and training institutions - must guide and shape the ways in which the new technologies are used. By itself the technology cannot drive development.

1.8 Two major considerations related to using the new technologies are discussed in the implementation section of the report. Institutional coordination on the part of the technology suppliers and users is imperative for the **effective planning of new technological systems,** whether at the departmental or the national level. Planning requirements are defined in order to assure that all issues - not just the technical, but also the financial, educational, and managerial - are dealt with on a timely basis. Sound planning lays the foundation for the effective use of communications in development projects. The **development communication process** supports the achievement of development goals through carefully tested use of media and messages.

1.9 **Through the programs of the U.S. Agency for International Development, the United States has long been a leader in development communication research and in**

the design and testing of communication/information technology and applications especially suited to rural areas. Its radio learning program, rural satellite program, and new initiatives in microcomputer use have laid the foundation for testing the viability of these systems and developing successful applications. USAID has also strongly supported training efforts in broadcast, telecommunications, and microcomputer use. **Congress should continue to support USAID's leadership role, so that appropriate applications can be developed for Africa.** Communications and information should form a component of all rural development projects, so that leaders come to understand the need for these services and to provide for related training, maintenance, and management services.

1.10 Over the next decade the critical challenge will be to institutionalize appropriate uses of these new technologies in Africa for the benefit of rural populations. It is African leaders themselves who must incorporate the commitment to train personnel, develop applications, manage systems, and maintain equipment. In partnership with the United States and the international development community, Africa can begin to "bridge the gap."

1.11 Other policy recommendations made in the final section include:

- The U.S. government needs to act in partnership with the international, regional, and national organizations that have communications programs.
- The U.S. government should seek to channel and mobilize the expertise of the U.S. private sector for application in meeting the communication needs of developing nations.
- The leaders of developing nations must make communication systems an important national priority and must communicate this sense of priority and urgency to international donor agencies.
- The U.S. government can act as an important catalyst in educating the leaders and policymakers of sub-Saharan Africa to the benefits of investment in communications and the dangers of neglect.
- The U.S. government should encourage and support training for the management capacities needed to run rural communication systems, as well as for all skills involved in designing, maintaining, and using these new systems.
- The U.S. government should work with African nations to assist them in formulating and articulating their technical needs on a regional basis, and the U.S. government should encourage U.S. private sector companies to meet the challenges of developing simple and rugged equipment for use in Africa.

SECTION II

COMMUNICATION AND INFORMATION TECHNOLOGIES

2.1 The new communication and information technologies - based on satellites for delivery and microcomputers for processing - can leapfrog the geographic obstacles which perpetuate the isolation of much of sub-Saharan Africa. Modern telecommunications can reach quickly and effectively where roads and cables cannot yet go. The small farmer telephones the district extension agent for information on a crop pest. The national planner has immediate access to current information on local yields. Agricultural extension agents all over a country receive training and technical support from the country's leading agricultural experts.

2.2 In Africa the promise of widespread communications - a public telephone within an hour's walk from any settlement - still remains a dream. Pieces of the technological puzzle decrease in cost and increase in adaptability each year. Pilot projects in other continents demonstrate both the potentials and the problems posed by an integrated rural communication system in a developing country.

2.3 Neither African governments nor African farmers have time to wait for roads to be built, schools to be opened, and teachers to be trained for education and information to reach Africa's rural populations. Africa needs more food now, and rural families (80 percent of the population) need to improve their basic welfare. How can the application of modern communication and information technologies support the livelihood of Africa's small farmers and enhance food production?

2.4 Three communication and information technologies - broadcast radio and television, satellite-based telecommunications, and microcomputers - are examined for their application in supporting low-resource agriculture in sub-Saharan Africa. Radio is discussed in its historical perspective as a medium that has been broadly available in Africa since the 1950s. Hundreds of development projects have used radio for communication and information transfer. Many countries in Africa now have their own television services, an enormous expense to a developing nation, but television has not had much impact on development communications because of its lack of availability in rural areas and the high cost of programming and equipment maintenance. The discussion of satellite-based communication systems and microcomputers - technologies that are often linked to provide comprehensive information and communication services - is oriented to the future in terms of their potential in Africa. Figure 2 in Appendix A shows communication facilities available in sub-Saharan Africa on a country-by-country basis as of 1984.

2.5 The use of any of these technologies needs to be viewed in light of the discussion in Section III on planning for communication systems and the development communication process. A piece of equipment - whether a radio or a microcomputer - should be acquired within a communication or information strategy. No strategy can succeed by itself alone. Development communication supports development efforts; it cannot sustain them.

BROADCAST RADIO AND TELEVISION

Current Status in Africa

2.6 With approximately 8 percent of the world's population, sub-Saharan Africa has only 2.4 percent of the world's radio receivers and 0.7 percent of the world's television receivers (UNESCO Statistical Yearbook, 1984). According to UNESCO figures, there are on the average 87 radio receivers per 1,000 inhabitants in sub-Saharan Africa. These figures, however, are unreliable, because no independent check is made of the figures submitted by national governments to UNESCO. The figures also mask great variations within Africa as to coverage by country, by urban and rural location, and the differential access by men and women to media in different settings (ethnic group and social class). Television is still an urban medium, whereas it is estimated that 70 percent of rural Africa now has radio coverage.

2.7 While most radio and television stations in North and South America are commercial, in Africa they are generally government-owned. African stations, since they are government-financed, do not conduct regular audience research studies; information on African audiences comes from Voice of America (VOA) and British Broadcasting Corporation (BBC) studies. The following table based on BBC data shows receiver penetration by world region and gives a comparative perspective on Africa's status in terms of access to radio and television. UNESCO tables in Appendix A give further information on the distribution of radio and television transmitters and receivers worldwide.

Table 1
RECEIVER PENETRATION BY WORLD REGIONS

	Number of Persons per Receiver	
Region	Radio	Television
North America	0.47	1.46
Australia and Other Ocean Territories	1.21	3.33
Western Europe	1.46	2.82
USSR and European Communist Group	1.65	3.39
West Indies	1.81	5.55
Latin America	3.17	8.08
Middle East	4.38	13.64
Asia and Far East	5.29	23.00
Africa (excluding North Africa)	8.16	36.57
World Total	2.58	7.25

Source: Based on data in BBC External Services, "World Radio and Television Receivers" (BBC, London, June 1983). From Sydney Head, World Broadcasting Services: A Comparative Analysis. Belmont, CA: Wadsworth Publishing Company, 1985, p.327.

2.8 Several African governments adopted radio and television as answers to the massive educational problems they faced after independence. Most adults were illiterate, and rapidly growing populations strained the capacities of schools and teachers to their utmost. For example, both the Ivory Coast and Niger instituted national educational television programs. In their first years, programming quality and foreign financing were high; as foreign support was withdrawn, programming declined in quality, and finally the efforts were halted. In hindsight, the large projects of the 1960s and 1970s failed to deliver their promise due to major faults in planning, programming, and understanding local conditions, according to experts in the field. Now, while the technical systems are in place, African planners are examining the prospects of using radio and television in support of development more cautiously and realistically.

Uses for Development

2.9 Project experience, acquired over the past twenty to thirty years, has shown that the use of mass media for educational and development support purposes can be successful under controlled conditions. The requisite conditions and considerations that lead to project success, however, are significant and often difficult to accomplish. In general, technical problems are the easiest to solve and paradoxically, therefore, have received the most attention. The provision of information makes a difference only when all other conditions support change in the behavior of the target audience. Careful planning and management, as well as the use of experts for program and instructional design, are critical components in achieving project success.

2.10 **Because of its relatively low costs and wide availability throughout rural areas, radio - not television - has been the medium of choice for agricultural projects.** Use of radio for development purposes falls into three major categories.

- **Distance Education:** Includes activities conducted in schools or community centers with the purpose of teaching - basic literacy and numeracy skills for adults; language, math, and science knowledge for schoolchildren.
- **Development Communication:** Includes activities that motivate participation in and provide information about development projects in agriculture and health, for example, with the goal of changed behaviors.
- **Interactive Communication:** Provides two-way communication for project management and information transfer.

2.11 In agriculture there are several critical flows of information - to the farmer, to the extension worker, and to the agricultural researcher. Ideally information flows from the farmer, also - proactively in terms of stating farmer needs and reactively in response to external conditions. In most developing countries, these flows of information have serious deficiencies. Agricultural officials and researchers, not to mention broadcasters, have little knowledge of the actual needs of low-resource farmers. Farmers have no channel through which to express their concerns. Underlying the problems in information flow is a fundamental lack of national commitment to the livelihood and welfare of small, traditional farmers (low-resource agriculturists) in contrast to large, modern agricultural producers.

2.12 Over the years that radio has been used to reach rural audiences with agricultural information, three major formats have been developed.

- **Open Broadcasting:** Provision of informational and educational programs - news, weather, crop practices, etc. - with no particular audience targeted.
- **Campaigns:** Radio messages broadcast for a specific period of time on a specific subject with the goal of changing a particular set of behaviors - pesticide use, for example.

- **Listening Groups (Radio Forum):** Organized groups that meet regularly to listen to, discuss, and plan actions on specific agriculture topics.

2.13 In appropriate project conditions, all three formats have proven effective. A major challenge, once a given project is finished, is sustaining media commitment to broadcast agricultural programs that are pertinent to local audiences.

2.14 Two new technological advances have greatly extended the reach of broadcast programs - the audiocassette and the videocassette. Projects are now incorporating these technologies to reach farmers who are out of the range of regular broadcasting and to provide a channel for farmer feedback.

Project Examples

2.15 A vast literature exists on the use of mass media in development generally and in agriculture specifically. Projects will be cited here only briefly; fuller documentation is provided in Appendix C. The focus of this section is not on the projects themselves, rather on the lessons they demonstrate about the effective use of mass media - in particular, radio.

2.16 The Masagana 99 project in the Philippines and the Basic Village Education Project in Guatamala directly incorporated communication strategies into overall project design. Information supplied by radio was vital to the successful implementation of farm practices advocated by the projects to increase productivity - the use of high-yielding rice varieties in the Philippines and the use of modern agricultural practices for basic grain crops in Guatemala. In each case, communication efforts supported a package of project inputs that made changes in farm practices practicable to farmers themselves. In each case, agricultural information was tied directly to the needs and conditions of farmers at a particular season, and farmer feedback was integral to project design.

2.17 Masagana 99, a vast national campaign, resulted in the transformation of the Philippines from a rice-importing to a rice-exporting nation. Communications efforts in agriculture have become well-established there, based on the successful short courses offered by radio during the campaign. Similarly, the use of radio in Guatemala - by itself and in coordination with assistance by agricultural monitors - proved effective in changing farmers' attitudes and in increasing their willingness to adopt new practices. Had the project been continued, projections showed that farmers would have experienced an 80 percent increase in yields after seven years.

2.18 Radio listening groups - farm forums - originated in Canada in the 1930s and have been widely used throughout the developing world, including Africa, as a primary means of bringing agricultural information to farmers. A major problem in the use of groups is their inherent instability, unless structured on traditional groupings which function strongly apart from radio listening activities.

2.19 While radio effectively bypasses the problem of literacy, a major challenge in Africa is broadcasting in the local languages of African farmers. Much of the programming takes place in the colonial languages of French or English. A new project - The Liberian Rural Communications Network - now offers broadcasting in 13 indigenous languages from sites located in rural areas. Programs are on subjects directly related to rural welfare - farming, forestry, nutrition, and health - and audience feedback results in 60 to 70 letters per day per station. Few other African broadcasting systems incorporate such a high degree of localization in terms of language, location, or subject matter. Financial support for the radio stations is increasingly coming from local and private sources, rather than the national government.

2.20 Agricultural projects that are targeted to specific groups have made use of local language programming and provided for farmer participation and feedback. In the Wonsuom project in Ghana, radio broadcasting is done in the Fante language; farmer discussions about the broadcasts and related development activities are recorded and used in subsequent broadcasts. Whether or not such efforts will be sustained once project support is completed remains problematic.

2.21 A new USAID project - Communication for Technology Transfer in Agriculture (CTTA) - will be based in nine sites worldwide. Possible sites in Africa include Swaziland, Cameroon, or Senegal. Its mandate is to improve the flow of information among farmers, extension agents, and agricultural researchers. Recent evaluations in Malawi, for example, have demonstrated a broadening gap between the information farmers want and the information the extension programs provide, despite their popularity.

2.22 One crucial element in producing effective programming for agricultural broadcasts - be they for radio, television, or video - is the training of broadcasters who understand rural audiences and their needs and who can work effectively with content specialists. Emphasis in training projects such as Swaziland Development Communications is not on the technical aspects of broadcasting but on strategies for incorporating communications into development efforts and on effective ways of reaching rural audiences.

2.23 An international information service based in Canada, Developing Countries Farm Radio Network (DCFRN), makes audiocassettes available to radio stations in over 100 countries. Programs present information on farm practices appropriate to poor farmers in order to improve welfare and productivity. Implementation costs are low, and new practices rely on local inputs alone. Information packages consist of radio scripts, a cassette with pre-recorded scripts, illustrations, and a newsletter. Programming is available in English, French, and Spanish; broadcasters are encouraged to submit local feedback, and their comments are used to develop future programs. It is estimated that these programs reach over 100 million radio listeners.

2.24 A unique experiment is underway in Niger, an early user of educational television. Niger has re-programmed this earlier effort to provide most of the country with a rural television network for nonformal adult education. Community centers around the country are provided with television sets, and programming is being broadcast in local languages. It is still too early to measure the success of this ambitious educational effort, but, because of its rural focus, it bears watching.

2.25 Finally, work is being done with video in villages around the world. Whereas television traditionally has represented a medium oriented toward elite urban audiences, video is a communication tool that can be appropriate for work with villagers - poor farmers and women, in particular. Since 1974, Peru has based its extension programs for rural farmers on the use of video. Teams of producers make agricultural courses that are distributed to local extension units. Each course incorporates several lessons, and the video is supported by print and graphic material as well as extensive discussion. Farmer feedback is critical to course production. Equipment has proved to be durable, and equipment costs are only 10 percent of total project costs. Nigeria's extension service also incorporates video in the programs it takes to villages; new videos of topical and timely interest are produced every two weeks.

2.26 Video is a tool for recording local realities and gives its makers important experience in project design, development, implementation, and evaluation. The Village Video Network, cosponsored by the United Nations University and Martha Stuart Communications, Inc., was founded in 1982 to promote the use of video as a tool for development and the exchange of tapes among member countries.

Benefits and Constraints

2.27 Broadcast media are able to sidestep the issue of literacy and present all information orally or visually - the customary means of communication in traditional African societies. **Radio's benefits for communication in Africa are readily apparent - low cost and wide reach. Television, on the other hand, is associated with high costs and narrow reach.**

2.28 Radio profits from its long history. The technologies for production, broadcast, and reception are all well-developed. Equipment is standardized and relatively inexpensive. In contrast, the use of television is still beset by technological complexities, including three major international standards and incompatible equipment. Radio producers deal only with voice; television producers must deal with finding appropriate footage and filming techniques to illustrate the audio content of shows. Production costs and limitations often force African television stations to make use of American entertainment shows, rather than locally-produced materials of relevance to local populations. While television has been effectively utilized in some instances, it requires such a high level of funding support and programming quality that its true potential in development communications has yet to be explored on a long-term basis.

2.29 Constraints, however, to the effective use of radio in support of agriculture must be considered. Most important is the quality of programming - not the sound, but the content. While broadcasters are concerned with development issues, limitations in financing and production capability preclude creative programming on development-related subjects. In general, only five percent of radio broadcast time in Africa is devoted to such subjects.

2.30 For radio to effectively support development efforts, broadcasters must get to know farmers in specific locales who have their own languages and their own problems. In agriculture, information about changes in behavior must be tuned to seasonal fluctuations in climate and crop growth. Changes are incremental, and increased productivity is not immediate.

2.31 The use of mass media must be integrated into ongoing agricultural projects, so that information suppports the provision of other inputs - seeds, fertilizer, credit. Also, the use of mass media must be integrated with other forms of communication - interpersonal exchange with agricultural field workers and supporting graphics material.

2.32 A particular constraint with mass media is determining who has access to it. This is a question not just of the strength of transmission, but of who owns radio receivers and who within a household or compound actually listens to the radio and when. Project planners must especially ascertain whether or not women have access to radios and, if they do, when they have time to listen.

2.33 The question of access is related to the question of targeted audience. If male extension workers focus on the activities of male farmers and if extension programming supports this focus, female farmers may be entirely untouched by development communication efforts.

2.34 A constant impediment to good development programming through the mass media is the lack of easily obtained feedback from farmers. Project planners need to build feedback channels into their communication strategies to ensure that they are meeting farmers' needs.

2.35 A final but critical caution regards the sustainability of programming on agricultural subjects. A strong project such as Masagana 99 provided the impetus for a strong communication campaign. But once a project ends and funding (usually from a donor, rather than a local agency) is no longer available, will programming continue? Highly creative and effective communication pieces may be produced within a project framework, but can that quality be institutionalized? The CTTA project (mentioned earlier) will work with extension units throughout the world in the attempt to institutionalize such quality on a continuous basis. Necessary components of this effort to insitutionalize agricultural communications are funding, training, and strong national commitment to reaching farmers, especially low-resource farmers.

Policy Issues

2.36 A few policy issues stand out as salient for the nations of sub-Saharan Africa as they continue to develop their broadcasting systems.

- **Commitment to Rural Development:** The national government must have a continuing and strong commitment to rural development in general and low-resource agriculture in particular.
- **Central versus Local Control:** Most broadcast facilities in Africa are government-controlled, and governments are loathe to relinquish control over communication and information. Effective localization, however, of development communications requires local programming in local languages.

- **Inter-Ministry Coordination:** Some institutional mechanism is needed to coordinate inter-ministry efforts, especially given the scarcity of resources for equipment and training in Africa. Development ministries need to cooperate with each other in the preparation of program materials and with the broadcasting services to receive technical assistance.

- **Target Audiences:** Programming topics and times will reflect the biases of broadcasters and development workers. Are issues that concern women as cultivators and mothers addressed? Are programs aired at times when farmers can listen? Are nomadic populations given consideration when priorities are established? Is variability within the target audience taken into consideration?

- **Power Sources:** Batteries are the common power source in sub-Saharan Africa where electricity is not yet available. In the current economic climate of foreign exchange shortage, some countries are producing batteries for export rather than domestic use. Batteries are becoming too expensive for many poor African villagers to buy and are a low-priority item in their struggle for survival.

Future Developments

2.37 While radio receivers themselves will only slowly undergo further modification, new technical developments are possible in the delivery system and power source.

- **Delivery:** Use of satellite-based delivery can greatly extend the range of radio and television transmission. Small earth stations in combination with microwave facilities can transmit broadcasts to rural areas previously inaccessible.

- **Power Sources:** Experiments with photovoltaic (solar cell) power systems have long proven successful. Solar power is especially suitable for the remote areas of Africa where requirements for electric power are low and widely dispersed. Photovoltaic power systems are modular, low in maintenance needs and costs, and longlasting.

  In 1980, UNESCO and the Economic Commission for Africa sponsored the development of a prototype rural radio system for Africa. The concept called for a receiver that would be low in cost and independent of frequent battery replacements. Porsche designed the solar-powered VHF/FM receiver, and UNESCO is negotiating with the People's Republic of China to mass produce the receivers for African markets. Available in Southern Africa on a trial basis in 1986, the receivers were sold for $20 U.S. apiece.[1]

- **Video:** As mentioned before, video is proving an adaptable and durable technology in rural settings. Training for video crews is simple compared to the training required for television. Playback is instantaneous and feedback immediate.

Conclusion

2.38 **For the foreseeable future, radio will continue to provide the most reliable and appropriate medium of access to low-resource agriculturists in sub-Saharan Africa.** The radio - in contrast to the telephone, television, or microcomputer - is already a common household object throughout the developing world. Most people are familiar with operating a radio and also the use of cassettes. The technology of radio production and broadcasting is relatively simple, and receivers in general are easily obtained and relatively inexpensive. While the nomadic populations of sub-Saharan Africa offer broadcasters a special challenge in terms of accessibility, the use of pre-recorded cassettes for distribution to such groups could further extend the reach of radio.

2.39 For reasons of cost and accessibility, thus, radio is the technology of choice for use in most projects that require development communications. It can be flexible, and it can be adapted to local needs and goals. **The significant challenge in broadcast remains the production of programming truly responsive to farmers' needs.**

2.39.1 Effective communication with farmers depends on knowing the targeted group of farmers: the way they perceive their livelihood and the means they feel they have to change it. Effective communication entails the use of feedback mechanisms which bring information from the farmer back to the agricultural extensionist, researcher, or broadcaster. All communication programs for agricultural purposes must be modified, changed, and expanded based on continual monitoring of farmer response and farmer need. This cyclical process - vital for the effective communication of information intended to change behavior - is built on the principles of anthropological research, behavioral analysis, and social marketing.

2.39.2 Changing agricultural practices is an especially challenging task because of the complexity over time of agricultural processes. Farmers do not realize immediate rewards to changing their farm practices, and changes in farm practices generally involve changes in other practices and relationships with the broader environment. The same challenge to agricultural communication exists in the United States as in the developing world. At its best, the U.S. Extension Service was extremely effective in working with farmers due to the close relationship extensionists had with farmers and their situations, so that information was presented to farmers when they needed it and in a form they could use.[2] (For a more detailed discussion of these issues, see "Development Communication Process" in Section III of this paper.)

SATELLITE-BASED TELECOMMUNICATIONS

2.40 Africa presents many obstacles to the development of terrestrial systems for communications and transportation. The African population is thinly settled across vast areas difficult to traverse because of the terrain - deserts, mountains, jungles, and rivers. Settlements are small, and many groups are nomadic, shifting in location to find pastures for their herds. Terrestrial communication systems are heirarchical, branch out from major urban centers, and are vulnerable to damange; thus, remote rural areas are the very endpoints in cable, broadcast, or microwave transmission systems.

2.41 Satellite transmission can circumvent these obstacles in delivering telecommunications services to rural areas. The deployment of small earth stations can link settlements to larger district and national centers. Narrowband technologies make possible the transmission of voice, video images, text, handwriting, and graphics over simple telephone lines.

2.42 The advantages of satellite transmission over terrestrial transmission systems (cable, broadcast, or microwave) are significant for sub-Saharan Africa.

- Satellite costs and operations are insensitive to distance.
- Reliability of the entire system is not affected by a failure at one down-link point in the network.
- Satellite connectivity to earth stations is direct rather than heirarchical.
- Small, inexpensive earth stations can be placed anywhere in a country and do not need to be connected to a ground line system. They can also be transportable.

Current Status in Arica

2.43 Numbers of telephones and the distribution of telephones are considered important indicators of economic development. Although Africa had an average annual growth rate of 8.7 percent in numbers of telephones during the 1970s, Africa's rate of population growth kept the number of telephones at a low level. In 1981 Africa (excluding South Africa, but including North Africa) had an average of 0.8 telephones per 100 people. This figure hides large discrepancies among nations and, especially, between urban and rural distribution. (See Table 8 in Appendix A.) Telephone services are concentrated in urban areas, typically in capital cities, and the development of new services focuses on meeting urban demand and linking district centers.

Table 2
TELEPHONES BY CONTINENTAL AREA

Continent	No. 1977	% of World	Per 100 Population
North America	168,362,000	42.3	70.7
Middle America	4,880,000	1.2	5.2
South America	9,856,000	2.5	4.5
Europe	143,871,000	36.1	19.1
Africa	1,895,000	0.4	0.4
Asia	59,426,000	14.9	5.2
Oceania	7,897,000	2.0	35.0
World	395,990,000		

Source: International Telecommunication Union, Transport and Communications Decade in Africa, Geneva, 1981.

2.44 The plans for the United Nations Transport and Communications Decade in Africa (1978-1987) set ambitious and comprehensive goals for the development of telecommunications there. These goals included telephone services - to be located no more than five kilometers from any settlement or one Public Call Station per 10,000 rural population - training, management, maintenance, and manufacturing. The PANAFTEL (Pan African Telecommunications) network facilitates direct intra-African communications without routing through Europe. PANAFTEL has authority now to offer assistance to its members in all aspects of telecommunications, from technical to human services development. Achievement of the UNTCDA goals is possible only through the use of satellite delivery systems which build on existing terrestrial systems.

2.45 While plans have been developed for an African satellite, the costs of such a system so far have precluded implementation. Most nations of sub-Saharan Africa are members of the International Telecommunications Satellite Organization (INTELSAT) and currently lease transponder services for international communications. Four nations have their own domestic satellite services which they lease from INTELSAT - Nigeria, Sudan, Zaire, and Niger. The map in Appendix B shows telecommunication routes in Africa and the location of earth stations.

Uses for Development

2.46 While planners and economists debate the exact role and value of telecommunications in Third World development, telecommunications and especially telephone services are recognized as part of the basic infrastructure of a nation - as basic as roads and water and power, for example. The availability of telecommunication services has vital implications for all sectors of development by allowing the two-way exchange of vital information. Telecommunications is one area of investment that generates substantial revenue, and its presence stimulates economic growth.

2.47 The specific technical services which satellite-transmission systems can extend to rural areas are described briefly below. Although these services can all be transmitted terrestrially, the time involved in system development would prohibit their application in most rural areas in the near future. Project examples that illustrate these uses in agricultural contexts are cited in the next section.

- **Telephone:** Telephone services provide for rapid information transfer and decision-making. Direct communication between field workers and district staff for agricultural projects greatly facilitates the management of schedules, resources, and activities. Investments in rural telecommunications, especially in areas that are already active sites of development projects, have high rates of economic and social return. Telephone services begin to link together a dispersed population. Of equal importance, they can often replace or reduce transportation services, thus resulting in important savings of time and fuel.

- **Graphics and Text:** Often as important as voice communications in project management or the provision of agricultural services is the rapid transmission of text. Documents and information of import to agricultural services such as marketing and credit can be exchanged quickly, allowing for the timely signing of contracts to authorize work or of decisions to purchase inputs by agricultural project managers, for example.

- **Teleconferencing:** Satellite-based communication can facilitate the linking of multiple sites for interactive exchange. Audio teleconferencing is limited to voice, but can be augmented for graphic exchange by means of slowscan video or electronic blackboards, for example.

- **Broadcasting:** Use of satellite transmission can greatly extend the range of radio and television broadcasting to areas inaccessible by regular broadcast or microwave transmission.

- **Two-Way Radio:** The use of dedicated radio frequencies allows for the development of a radio communications network to link field workers scattered across wide distances. This application has been used primarily in health care, but it is equally appropriate for agriculture.

- **Data Communications:** Satellite transmission of data between microcomputers greatly facilitates sharing of research results. While communication among users is not interactive, it does allow for written requests and responses. Electronic mail provides a similar service.

- **Remote Sensing:** The use of satellite imagery in combination with agronomic, topographic, and climatic information can provide a powerful tool for monitoring crop growth and water resources. Such information assists in the prediction of drought and pest attacks and contributes to "early warning systems."

2.48 Ongoing technological developments have made the three technical systems involved in satellite-based telecommunications - the satellite, the earth station, and the switching or distribution system - increasingly appropriate to the conditions of rural Africa. Satellite beams are more powerful; earth stations are smaller; solar panels can replace the use of electricity or fuel as power sources; earth stations can function as receivers alone or as both receivers and transmitters of programming. Thus, the technology is becoming less expensive and more adaptable to the specific environmental requirements of sub-Saharan Africa.

2.49 The implementation of satellite-based rural telecommunication systems can further the achievement of three major development goals - efficiency, effectiveness, and equity. By improving the management of rural development projects in all sectors, telecommunications contribute to **efficiency**. By facilitating the timeliness of information regarding resource demand and availability, telecommunications contribute to **effectiveness**. And by bringing information and experience to geographic areas and population groups isolated from national development, telecommunications can improve **equity**.

Project Examples

2.50 The history of the use of satellite-based telecommunication systems to deliver educational, instructional, and social services to isolated populations begins in the early 1970s. Alaska and Canada instituted broad programs of two-way radio, educational television, and audioconferencing to provide their citizens in remote rural settlements with basic health care and education. The Alaska system now includes more than 100 television receive sites, 100 telephony earth stations, an extensive health care network with a computerized medical information system, an educational television channel, and a statewide audioconferencing network. The Canadian system provides much the same services, in addition to an Eskimo broadcasting and teleconferencing network, a unique experiment in indigenous programming.

2.51 India also pioneered the use of modern rural communication systems in the Satellite Instructional Television Experiment (SITE). During 1975-76 SITE provided in-school and adult education to 2,400 villages across India, using programs produced by the TV production unit of All India Radio. Both the television receivers and the earth stations were manufactured in India. Through its INSAT system, which became operational in 1983, India is continuing to build its capacity in the hardware and software development needed for rural communication systems.

2.52 Beginning in 1981, the U.S. Agency for International Development funded a six-year experimental program in the appropriate applications of satellite communications to rural development. The Rural Satellite Program included three pilot projects, information services, policy studies, training, evaluation, and research on the development of photovoltaic energy and inexpensive small earth stations. The pilot projects in Indonesia, the West Indies, and Peru addressed the needs of rural development at different levels of infrastructure, institutions, and personnel. The pilot projects made use of narrowband technologies and built onto existing land-based communications infrastructure.

2.53 The Indonesia project linked ten universities and the National Institute for Agriculture in a network with audioconferencing capabilities for the teaching of courses, presentation of seminars, faculty development programs, and administrative meetings. The course-sharing program reached 3,000 students per week, while staff development activities such as an agricultural sciences seminar series involved 1,200 personnel from the ten institutions across 2,500 miles of Indonesia. The West Indies project linked the scattered campuses of the University of the West Indies to provide distance education for extra-mural students, in-service training for teachers and medical personnel, and outreach programs for agricultural extension workers. Both projects are expanding their services and the number of sites at the end of the pilot phase.

2.54 The Peru Rural Communication Service Project is the most rural-oriented of the three pilot projects. It is located in an economically and agriculturally active region of Peru, which was isolated from modern communication services by the Andes. The project provides basic telephone services to seven communities through three earth stations and VHF links. It also provides audioconferencing capabilities and facilities to these seven communities, in addition to linkages with Lima. While the telephone services were offered at basic commercial fees, the audioconferencing was provided free-of-charge to the user ministries - agriculture, health, and education - for two years in order to accustom them to using new communication technologies for training, coordination, and administration. By the end of the second year, agricultural extension meetings were being held regularly once a week. Telephone services were heavily used by businesses in the area, as well as by local residents. In 1985 over 100,000 telephone calls were made; 94 percent originated in the rural sites, and two-thirds of the area's families made use of the telephone services.

2.55 **What lessons emerge from these projects? Basic telephone services lead to the greatest economic and social returns of any investment in rural communication systems.** There is a great demand for telephone services in rural areas, as shown by the Peru project. Planning and provision of services should be based on the end-users' perceptions of need; telephone services are highly valued by both rural citizens and enterprises.

2.55.1 Recent studies commissioned by the International Telecommunication Union were undertaken by Communications Studies and Planning International Ltd. to establish the benefit/cost ratio of investments in telecommunications. In Costa Rica, the benefit/cost ratio for all categories of users was 48:1 and for all classes of residential users was 5:1. In the Philippines, the benefit /cost radio for small business users exceeded 20 to 1. The use of telephone services enhanced the efficiency of businesses, even small village and home-run enterprises, in the following ways:

- expansion of business
- increase in sales prices
- decrease in purchasing prices of supplies
- decrease in inventory levels
- coordination of use of vehicles
- rapid repair of equipment
- savings on labor and managerial time.[3]

2.55.2 Telecommunication networks do not replace interpersonal networks; rather they permit existing institutions and enterprises to extend their coverage effectively. An agricultural extension service that uses telephone services for administrative and managerial purposes can reach many more farmers effectively and efficiently. Rapid communication makes the delivery of timely information possible and greatly enhances the range of work an extension agent can perform. At only marginal costs, a telephone system can be modified to perform as a training system, also.

2.56 Inherent in new communication technologies are new communication processes. Audioconferencing offers the advantage of interaction, which broadcast does not allow. Teachers, managers, extension agents - whatever personnel are involved in leading audioconferencing sessions - can easily be trained to make effective use of the system. **The Rural Satellite Program showed that multi-site audioconferencing can be a cost-effective and efficient tool for training, information exchange, and management.** In response to interest expressed by parents, for example, the Peru project developed an audioconferencing program in special education.

2.57 Strong leadership at the national level and in service provider and service user agencies is critical to the success of rural communication projects. Such projects must be based in existing institutions in order to succeed. In Peru, the project is carried out by the national telecommunications authority, ENTEL/Peru, which has established a new program office to oversee the development of *rural* applications. ENTEL/Peru now plans to extend similar services to 53 more communities in the Andes region.

2.58 All telecommunications projects in developing countries experience the need for extensive training of personnel. The *U.S. Telecommunications Training Institute* (USTTI) was established in 1982 as a joint venture between the U.S. government and the U.S. telecommunications industry to address the training needs of developing countries. In 1985, USTTI offered 26 courses and graduated 196 telecommunications managers and technical experts who operate telephone and broadcast systems around the world. Courses are offered in seven categories: broadcasting, data communications, management, network planning/management, satellite communications, spectrum management, and switching systems. Training is provided tuition-free by the thirty U.S. member corporations at their corporate sites. National governments or donor agencies provide travel and support funding for the participants.

Benefits and Constraints

2.59 As previously mentioned, **satellite-based communication systems offer significant technical advantages over land-based systems for sub-Saharan Africa.** Small earth stations, built to withstand the rigors of African climates while using the sun for power, could be almost maintenance-free, since equipment would use boards easily replaced and then shipped to maintenance centers for repair. The costs of expensive microwave relay systems would be circumvented and technical problems in the use of land lines would be avoided. Thus, in the best of all technological worlds, rural communication via satellite offers large benefits, both economic and social.

2.60 Many constraints, however, still impede the development of such systems throughout sub-Saharan Africa: cost, management, institutional commitment and cooperation, and appropriate uses for rural development. One writer (Stover, 1984) has characterized the major obstacles in the development of satellite-based rural communication systems as money and trust. Major funding is needed for the leasing of satellite services from INTELSAT and the construction of earth stations to meet INTELSAT specifications. Recurrent funding is needed for systems maintenance, programming, training, and management. While the benefits of satellite-based rural telecommunications will exceed their costs in the long run compared to the construction of land-based telecommunication systems or to providing no communication systems at all, the costs in foreign exchange and local currency are still formidable and require major international, regional, and national commitments. Regional cooperation among neighboring countries of Africa could offer many economies of scale - the shared leasing of satellite service, the shared distribution of spare parts and maintenance of equipment, and bulk purchase and production of small earth stations.

2.61 Institutional problems have arisen that relate specifically to the structure and authority of national telecommunications authorities. In general, although they do generate revenue from international services, they lack the autonomy to apply these funds to rural system development; they are required to turn funds over to the central government. Critical, also, is inter-ministry coordination between national telecommunications authorities and the user ministries of agriculture, health, and education to develop applications of true benefit to farmers.

2.62 Ongoing research shows the microeconomic benefits of communication and information services in agriculture. These benefits accrue from improved knowledge about prices, markets, and logistics; the ability to save on transportation and energy costs; and the increased willingness of private and public sector activities to operate in rural areas once communication linkages are available.

2.62.1 Not only has the overall economic efficiency of telecommunications systems been established, but its specific benefits in agricultural development are now being documented. Farmers, extensionists, and rural development managers can all achieve important savings in time and energy costs through the use of telephone services. Of all the sectors involved in rural development, agriculture has the broadest network of connections with other sectors. Research on telephone use by sector shows that, even though agriculture has the lowest overall rate of use, it has the broadest reach. Farmers and extensionists must coordinate resources with suppliers, buyers, creditors, and transporters. If resources are coordinated in an efficient and timely manner, farmers receive seeds when they need them for planting and can locate the highest market prices available for their crops when they are ready to sell. If communication among members, managers, and outside markets is possible, agricultural cooperatives can function effectively. In rural areas of developing countries, there is wide overlap in the use of telephone services for productive purposes by business, residential, and public call station users.[4]

Policy Issues

2.63 While macroeconomic studies are beginning to show a causal relationship between telecommunication investment and economic development, it is widely accepted that development cannot take place in the absence of communication. Consideration of macroeconomic issues leads directly into policy decisions which the nations of sub-Saharan Africa must make concerning rural satellite-based telecommunications. Governments must face the following issues:

- **Funding:** National governments must make the commitment to borrow or commit the foreign exchange needed to develop rural telecommunications systems, and governments must grant telecommunications ministries the autonomy to use their excess revenues for service development. Tariffs on regional and national levels must be negotiated to enhance rather inhibit rural system development. The Equator Bank has started an innovative funding program to assist African nations in joining INTELSAT. It pays the INTELSAT membership fee, using the new member nation's annual interest payment from INTELSAT as collateral on the loan.

- **Allocation of Frequencies for Satellite Broadcasting:** Currently a major political struggle is being waged between developing nations and the United States over allocation of wave frequencies for communication transmission. Frequency allocation is regulated by the World Administrative Radio Conferences (WARC), which traditionally have assigned frequencies on a "first come, first served" basis. Now, the developing countries are demanding a larger share of frequencies, even though they are not yet ready to use them. In a related issue, developing nations are claiming space in the geosynchronous orbit to hold in reserve until they are ready to make use of their own domestic satellites. These issues were the main focus of the 1985 WARC and as yet are not fully resolved.

- **Cross-Border Data Flow:** Nations regard information about their resources as private, but in the face of new information technologies - satellite imagery and database communications - access to such information is becoming more and more difficult to control.

- **Sources of Hardware and Software:** Currently most equipment and programming for telecommunication systems is produced in the developed countries. When developing countries are involved in production it is in assembly, not manufacturing. Thus rare foreign exchange must be committed for telecommunications projects, and developing nations remain dependent on outside sources to supply their technical needs.

- **Regional Cooperation:** Given the varied sizes and levels of development of African nations, major communication projects may be feasible only on a regional, cooperative basis. Nations must examine their willingness to cooperate, as well as the political stability of neighboring countries. Through bulk orders of equipment, nations could achieve significant economies of scale in the costs of establishing and maintaining satellite-based telecommunication systems.

Future Developments

2.64 Major international organizations such as the International Telecommunications Satellite Organization (INTELSAT) and the World Meteorological Organization (WMO) and U.S. organizations such as the National Oceanic and Atmospheric Administration (NOAA) are seeking ways to make their technologies more useful to developing nations, which face significant economic and environmental obstacles to development.

- **The International Telecommunications Satellite Organization (INTELSAT),** the global commercial satellite system, has developed a new service for rural telephony needs. VISTA was introduced in 1983 and relies on the use of small earth stations of simple design and low power consumption. INTELSAT's Assistance and Development Program works with developing nations to assist in network design and implementation planning. VISTA provides the user with flexibility in lease-time (minimum of three months), portability of earth station, and adaptability in uses (interaction and broadcast).

  In another effort to reach developing nations, INTELSAT began Project SHARE (Satellites for Health and Rural Education) with the International Institute of Communications in 1984. Project SHARE gives selected pilot projects for developing nations free satellite services for applications in health and education. Participating countries are reponsible for securing financial support and for providing terrestrial links. Currently 37 pilot projects are underway - from a TV University in the People's Republic of China to telemedical conferences between doctors at Miami Children's Hospital and medical practitioners in Latin America.

  One pilot project currently being planned would link the national offices of the Pan African News Agency (PANA) for the exchange of news and information. In the first phase of the project, regional PANA headquarters in Kenya, Libya, Nigeria, Sudan, Zaire, and Zambia would be connected through existing INTELSAT earth stations and appropriate microcomputer equipment.

- **National Oceanic and Atmospheric Administration (NOAA):** NOAA is providing its remote sensing services to developing nations. In Africa, remote sensing is used to monitor vegetation growth in order to predict crop yields and droughts. Such information, along with rainfall information provided by the World Meteorological Organization, is beginning to be integrated into "famine early warning" efforts.

  In another application of remote sensing, NOAA is assisting the International Livestock Center for Africa in Ethiopia to develop a monitoring and warning system for drought conditions in the Sahel.

  Finally, in order to train African researchers and scientists in the use of satellite imagery data, USAID has established two regional remote sensing centers in Africa - one in Nairobi, Kenya and the other in Ouagadougou, Burkina Faso.

- **Low-Earth Orbit Satellites:** Experiments are currently underway by VITA and AMSAT (Radio Amateur Satellite Corporation) to develop a low-earth orbit (LEO) satellite to test its applications for rural development. A LEO satellite would pass over each point on earth at least twice a day; at those times packets of information could be transmitted to or received from small earth stations. This system - called PACSAT for the packet format in which information is sent - does not provide synchronous interaction; rather its purpose is the storage and transmission of information - "an orbital postman". The PACSAT earth station consists of simple transmitting and receiving equipment, a small personal computer, and a vertical antenna. The earth stations are solar-powered and portable; their cost is about $2,000, in contrast to $40,000 for an INTELSAT VISTA earth station. VITA is working on promoting PACSAT's applications for supplying information for agronomic diagnosis and livestock feed sources, for providing database access, and for selecting appropriate agriculture computer programs for user needs.

Conclusion

2.65 While developed nations currently allocate 12 percent of their annual capital investment to telecommunications, less than 2 percent of all World Bank assistance to developing nations is invested in telecommunications. Rapid technological change is increasing the gap between Africa and the industrialized world, as well as between urban and rural areas in Africa. **Not until African leaders commit themselves fully to the development of rural telecommunication systems will the international banks and donor agencies also do so.** Although satellite-based telecommunications potentially offer significant benefits to rural Africa, the challenges of funding, designing, installing, maintaining, and managing such systems are still immense. The challenges are not only technical, but, more importantly, human and institutional.

2.66 In 1980-81, the International Telecommunication Union (ITU) undertook a pre-feasibility study of appropriate modern telecommunications technology for the integrated development of Africa and concluded that the use of a satellite delivery system would be viable. Since then, new technical developments have significantly lowered the costs and increased the adaptability of satellite, earth station, and distribution equipment. In 1986, an all-African Conference of Ministers of Transport, Communications, and Planning commissioned a feasibility study for a regional African satellite communication system (RASCOM). This study will examine all elements critical to a successful telecommunication system - local terrestrial networks, management, maintenance, and training, in addition to the satellite technology. The ITU is responsible for carrying out the feasibility study, which will include national and regional surveys of existing communication systems and needs. The study, expected to begin in 1987, will take two years.[5]

2.66.1 A similar effort has been underway since 1981, under the auspices of EUROSPACE, the European Space Agency. The European Development Fund provided funding for two studies: the first, in 1981, of the communication requirements of African nations and the second, in 1983, a pre-feasibility study for an African continental satellite system, AFSAT. No further action was taken until 1986 when steps were made to initiate a full-scale feasibility study. Zimbabwe and Nigeria have applied to the African Development Bank for funding for the study.[6]

2.67 Satellite-based telecommunications represent a system for the future in Africa. While study after study is done, the nations of Africa will expand the infrastructure of their telecommunication systems by making use of existing facilities, such as those available through INTELSAT. Discussions and studies will continue on the feasibility of an African satellite. The development of an integrated rural telecommunication system for the nations of Africa calls for international and national commitments of time, funding, and personnel on a level rarely achieved in traditional development programs. A satellite, it is felt, bestows prestige and glamour on a nation, but by itself it cannot bestow development.

MICROCOMPUTERS

2.68 Informatics (the use of microcomputers for information storage and processing) and telematics (the use of microcomputers for communication of information) are rapidly transforming information systems around the world. In the developed world, the United States and Japan lead the way in development of hardware and software. In the developing world, wide discrepancies exist between the nations of Asia, such as India and Korea, that are active designers and producers of hardware and software and the nations of Africa that are just beginning to introduce microcomputers into their institutional infrastructures. Wide discrepancies exist, too, among the nations of sub-Saharan Africa in the availability of microcomputer technology and the range of applications for which it is used.

Status in Africa

2.69 Microcomputers are becoming familiar tools in the development and government sectors of some countries of sub-Saharan Africa. Microcomputers have been brought in by individual consultants and by donor agencies; African officials who have studied abroad are acquainted with their use. Current data which show the penetration of Africa by microcomputers are hard to find. Similarly little comprehensive information exists to document the ways in which microcomputers are used. In cases where donor agencies are supplying government institutions and development projects with microcomputers, the principal uses are for word processing, spreadsheets, and database management.

2.70 In some of the more developed countries of sub-Saharan Africa, the private sector is leading the way in the introduction of microcomputers. For example, Zimbabwe, Kenya, Ivory Coast, and Nigeria have strong indigenous private sector firms which deal in the importation, marketing, and servicing of microcomputers. In general, the private sectors of African nations offer a more adaptive environment for technology transfer than do the government sectors.

2.71 In contrast to the few more developed nations mentioned above, many other African nations not only have relatively few microcomputers, but, more importantly, lack the infrastructure to support widespread microcomputer use. If microcomputers are to be used for more than word processing, especially if they are to be interconnected among departments and institutions and cities, a reliable telecommunications network is essential.

2.72 Essential, also, to this infrastructure are personnel trained in systems design, data collection, and data analysis. Information by itself cannot improve government planning or project management. Policy and decision makers must understand the potential power of microcomputers and the breadth of applications; national political support is critical to the development of the infrastructure necessary for the productive use of microcomputers. While most sub-Saharan African nations will not be involved in the manufacture of hardware, they need to develop service sectors capable of providing maintenance and spare parts. There must be personnel able to adapt software to the needs of local users and to program new software. Governments must set policies and regulations for the procurement of microcomputer equipment that complement national development policies. Strict restrictions on the importation of equipment hinder the innovative use of microcomputers.

2.73 The shortage of foreign exchange to purchase imported goods is a serious problem throughout sub-Saharan Africa. Just as batteries are difficult to obtain for transistor radios because of import restrictions, so, too, are supplies of tapes, cards, hard disks, floppy disks, paper, and printer ribbons needed for microcomputer use.

2.74 Even though the actual number of microcomputers in each African nation, particularly in the capital cities, is increasing, development of a support system in most nations lags behind seriously. As with any new technology, the capabilities of microcomputers have been developed more rapidly than the capabilities of human beings and institutions to utilize and apply them.

Uses for Development

2.75 The major uses of microcomputers have been noted already - word processing, spreadsheets, and database management - as have the primary contexts in which microcomputers have been put to use in sub-Saharan Africa - government institutions, development projects, and private sector businesses, all of which only indirectly reach low-resource farmers. In ministries such as education that must handle large amounts of information rapidly on an annual basis, microcomputers are being used to manage the data and assist in the planning process. Broader uses, including computer conferencing and accessing of international databases, are still at the earliest stages of use in sub-Saharan Africa.

2.76 The general uses of microcomputers in agriculture reflect these trends. Ministries of agriculture may acquire microcomputers to assist in **institutional management.** Agricultural and integrated rural development projects may use microcomputers for **project management,** particularly to process reports, accounts, and inventories.

2.77 In the developed countries, computers are widely used for agricultural teaching and extension. This is not so in Africa. There, microcomputer use begins with management and extends to research. Both universities and extension services are poor in technical and human resources and are not able to afford to purchase new technology or to develop applications should they gain access to microcomputers.

2.78 **Agricultural software in general is extremely limited in its applicability, because agricultural conditions vary so widely, but some new software has broader uses.** MSTAT, developed at Michigan State University, has general applicability in agricultural research. MSTAT can be used to aid the design of experiments; to print field maps, labels, and notebooks; to record experimental data; to manipulate data, and to perform statistical analyses. Another software program, MULBUD, which was developed in Australia, is used in agroforestry and complex cropping schemes to analyze the economics of different cropping patterns.

2.79 Although microprocessors are widely used in developed countries as control mechanisms for irrigation systems and food processing activities, these uses are not yet applicable to settings in sub-Saharan Africa where all farm labor is done manually and few resources exist for capital investment.

Project Examples

2.80 While it is difficult to find case studies of agricultural projects in sub-Saharan Africa which utilize microcomputers, brief mentions of microcomputer use appear in many articles. In general, articles that promote microcomputers for farm use in accounting, communicating, or modelling offer guidelines based on conditions in developed countries that are hardly suitable to the contexts of African low-resource farmers. The writers of these articles tend to offer little discussion of the difficulty in maintaining a reliable source of power; protecting the microcomputer from heat, humidity, or dust, or locating reliable service centers. In contrast, case studies of computerizing national budgets discuss in detail the major infrastructural obstacles to successful microcomputer use in sub-Saharan Africa.

2.81 **Project uses cited here include institutional management, project management, processing of agricultural survey data, computer conferencing for agricultural researchers, and computerized information bases and databases.** Of import are the lessons learned from these projects; the lessons, not the hardware/software specifications, are generalizeable. (Because these examples are drawn from books and journals and have not been documented yet by the Clearinghouse for Development Communications, sources will be cited for each project mentioned.)

2.82 The Ministries of Agriculture and Livestock Development in Kenya have experimented with and instituted microcomputer use for budgeting and financial management. Assisted by the Harvard Institute of International Development, the Ministries developed new systems for expenditure reporting, budget overexpenditure decision-making, budget estimating, and external aid claims. The project report lists several significant criteria for the successful institutionalization of microcomputer use:

- o Local managers themselves demand output.
- o Local workers handle all computer operations.
- o Local programmers do all programming.
- o The Civil Service retains capable computer operators.
- o Internal budgets provide for maintenance and supplies. (Munasinghe, p.68.)

2.83 In Nigeria a large integrated rural development project is currently making extensive use of microcomputers for project management functions - payroll and personnel, accounts, vehicle fleet control - as well as specific functions related to agriculture (Freeland, p.9). Agricultural databases include information on every farmer and field in the project. The information is linked to a calendar of crop tasks to produce farm management reports that assist extension workers in introducing farmers to new agricultural techniques. This database is also linked to critical input information so that inputs will be available on a timely basis.

2.84 The Statistical Reporting Service of the U.S. Department of Agriculture (Ingle, pp.124-28) has worked with many agricultural ministries in the developing world to assist them in the processing and analysis of survey data. While surveys have been widely used to gather information, it often took years for the data to be processed. By the time results were available, they were out-of-date and of no use to decision-makers. Even in countries where mainframe computers were available, agricultural surveys were of low priority and long delays occurred in data-processing. Microcomputers make possible the rapid processing of data, so that results can be given to project managers or national planners on a timely basis. Two major problems still exist, however. There must be personnel who are skilled in data analysis to analyze and report the survey results. And national planners, as well as project managers, must understand the value of information and know how to incorporate it in their decision-making processes.

2.85 The International Development Research Centre (IDRC) of Canada is assisting the International Agricultural Research Centers to develop an electronic data transfer and messaging network (The IDRC Reports, April 1986, p.6). This network, CGNET, went into operation in 1984, linking eight of the major international agricultural research sites along with many of the national agricultural centers and groups with which the centers conduct business. Since then the network has expanded greatly and is heavily used by the international agricultural community of research centers, development agencies, donors, and universities. In Africa, however, CGNET is not yet widely used. Only two of the five international research centers are members of CGNET: ILRAD in Nairobi and the Sahelian center of ICRISAT outside Niamey, Niger. The other international centers and the national programs do not use the network either because they lack the necessary communications infrastructure or because they choose not to for conscious political reasons.[7]

2.86 Microcomputers can be valuable tools in handling large amounts of information. IDRC has assisted in the development of both general (agriculture) and specific (cassava) collections of information (IDRC, 1986, pp.49-54). Worldwide computerized information systems for agriculture (AGRIS) and development (DEVSIS) document all published materials in the respective areas of research. AGRIS (the International Informational System for Agricultural Sciences and Technology) is run by the Food and Agriculture Organization of the United Nations and is divided into regional and national sub-systems. IDRC assists developing nations in becoming active participants in AGRIS. Similarly, DEVSIS (Development Science Information Systems) supports regional systems, such as PADIS in Africa. IDRC has also supported the development of subject-specific information systems - for example, Livestock in Africa through the International Livestock Centre for Africa. Through these systems researchers and scientists in Africa can have direct access to information and expertise worldwide in their particular fields.

Benefits and Constraints

2.87 Microcomputers, singly and in networks, make information available for access, storage, processing, and transmission in a revolutionary manner. Microcomputers can handle text, numbers, and graphics and can perform complex functions with the information. In contrast to mainframe computers, microcomputers are highly portable and durable. New models are decreasing in size and increasing in memory all the time. Software is becoming more and more user-friendly, making microcomputers an attractive tool for agricultural management and research applications. **The speed with which microcomputers work and the volume of information which they can handle have profound implications for institutional management and decision-making systems.** For example, the cooperative marketing boards in Zimbabwe are now making use of microcomputers to monitor prices and process payments to small farmers rapidly. Microcomputers there have contributed to strengthening the cooperatives and to integrating small farmers into national marketing systems.

2.88 **In many of the sub-Saharan African nations, however, two powerful constraints stand out - the human and the technical - to realizing the potential of microcomputers.** Microcomputers demand users who are literate, who appreciate the value of information, and who can use information - whether for analysis, communications, or decision-making. In general, rural African populations are illiterate, and Africa lacks skilled personnel in the areas of scientific research and development, modern management, and national policy-making. In this situation microcomputers are most often used as a substitute for typewriters, while their capacities for accessing and processing information go unutilized. Similarly, Africa also lacks the personnel to design software or to service hardware. Most African nations still look to the developed world to provide expertise in system design, choice of hardware and software, training, and maintenance. Over the next decade this situation may begin to change, as the use of microcomputers seems to encourage the development of literacy, management, and technical skills on the part of users.

2.89 On the technical side, while the lack of a reliable power source (stable electricity without power surges, for example) used to plague the use of microcomputers in Africa, a new device, the Uninterrupted Power Supply (U.P.S.), generally eliminates this problem. The U.P.S., however, adds considerably to the cost of a microcomputer system. The African environment is not kind to high technology, and the lack of air conditioning in many situations precludes the use of some kinds of microcomputers. The current poor condition of telephone lines in most African cities is a constraint to the use of microcomputers for communication, although adjustments can be made in baud rates in order to transmit information successfully. In most African nations the use of microcomputers for computer networks or computer conferencing still depends on the sophistication and quality of the telecommunications systems.

2.90 Thus far, microcomputers in the public sector of African nations have generally been used under the aegis of a donor agency, a sponsor from a developed country. Not enough time has passed yet to assess the results of projects that involve microcomputer use. Successful transfer of technology has come about through close collaboration with the end user and "action training" that trains the user in the specific tasks to be performed. The needs of the user should assume primacy, not the desires of a donor or a high government official. Equipment should not be experimental; training should be intensive, and support extensive. Adaptations and modifications of the system - both hardware and software - should take place on location. Little information exists yet on the sustainability of foreign-donated microcomputer systems. Equipment may break down; trained personnel may be transferred; changes in leadership may bring changes in priority and focus.

2.91 The more far-reaching uses of microcomputers in Africa in support of agricultural research and communications must await the maturing of Africa's scientific community. It will take time to design, gather, and process data, and to analyze results for high-quality African databases on agriculture and livestock. It will take time, also, to train African scientists to be active participants in the exchange of research information among the countries of Africa and worldwide.

Policy Issues

2.92 The nations of sub-Saharan Africa face several sets of policy issues related to the import, use, and impact of microcomputers. Issues are technical, organizational, and societal. They concern the relationships among nations, institutions, and workers. Currently few developing nations have comprehensive information policies. All the literature stresses the need for policy, so that microcomputers enter a society in a planned and systematic fashion, rather than on an ad hoc basis.

2.93 Great advances have been made over the past few years in dealing with the following technical issues:

- **Standardization and Compatability:** Rapid technical developments in the design of hardware and software create some problems for users in terms of what software will work with what hardware and what systems can be interrelated. Although no formal international standards exist in the microcomputer industry, standards have emerged in the marketplace because of the companies that dominate manufacturing, and international telecommunication standards apply to the communication capabilities of microcomputers.

- **Maintenance and Servicing:** Without assurance of maintenance support, a microcomputer system is worthless. Once malfunctioning, it will be out of use indefinitely. It will become one more piece of equipment littering the developing world for lack of servicing. It is essential for African nations to develop service sectors for microcomputers.

- **Power Supply and Telecommunication Links:** The full use of the microcomputer's capabilities depends on a reliable supply of power ("clean" rather than "dirty" power) and adequate telephone lines. Without power, the microcomputers cannot function at all; without telephone lines, microcomputers cannot be linked in networks for communications. Microcomputers now can be powered by solar cells, which can be assembled locally in Africa, and the use of U.P.S. devices can control for power surges.

2.94 Other issues relate to national development policies regarding labor force employment, human resource development, industrialization, and centralization versus decentralization of authority.

- **Industrial Development:** Microcomputers function in a nation's plan for industrial development. Does the nation plan to be involved in the manufacture or assembly of microcomputers? Is it protecting an infant industry or the idea of an industry by restricting the import of microcomputers?

- **Import Policy:** Through its import regulations nations effectively control the ease with which microcomputers can enter. Nations may differ in their motives for restricting imports, but the effect is similar: a blockage of creative adaptation and application of microcomputers, an increase in isolation from worldwide developments in the information industry.

- **Labor Displacement and Human Resource Development:** Many developing nations with an excess of manpower fear the potential of microcomputer technology to displace labor on a significant and harmful level. Some nations have even attempted to block the use of microcomputers entirely. Instead, developing nations should begin planning for the new kinds of jobs for which microcomputers will create a demand.

- **Allocation of Foreign Exchange:** Now that all African nations are suffering from shortages of foreign exchange, microcomputers compete as one item among many that must be purchased with foreign exchange. Governments are able to control who has access to microcomputers through their control over expenditures of foreign exchange. Some nations, such as Zambia, have relaxed import and foreign exchange regulations, so that new technologies can more easily enter.

- **Centralization of Authority:** Most governments of developing countries value centralized control over information and communication. While microcomputers could theoretically bring institutional handling of information to lower levels, government authorities will determine how microcomputers are used.

2.95 Finally, certain policy issues relate to international concerns - in particular, the international marketplace for which microcomputers are developed and international data flows.

- **Transborder Data Flows:** As microcomputers come to be used more and more for communication purposes - the networking of users and the sharing of information resources - data come to be a public good. Developing nations now have little control over other nations' access to their data. The need for international regulations concerning ownership and flow of information is becoming an issue of critical concern to all nations - developed and developing alike.

- **International Marketplace:** Currently most hardware and software are designed and produced in the developed countries. Only a few nations in the developing world such as India, Korea, and Brazil are independent producers of microcomputer technology. Most equipment and programs are not designed for conditions in the developing world, much less sub-Saharan Africa. The first assembly of microcomputers in Africa has just begun in Cameroon; it is expected to make a major impact on the microcomputer scene in Africa.

Future Developments

2.96 Microcomputer technology for informatics and telematics is undergoing rapid development. Equipment becomes obsolete from one year to the next. Increasingly the intertwining of microcomputers and telecommunication technology is producing revolutionary changes in the ways information is handled, stored, and transmitted. Only a few developments with key potential to impact on Africa are mentioned below.

- **From Analog to Digital:** Traditional telecommunications equipment is analog. Now with the increasing use of microcomputers for communication purposes, more and more information is transmitted digitally. African nations, still in the early stages of developing their telecommunication infrastructure, fear being left with obsolete analog equipment while the rest of the world makes use of digital communication systems.

- **User-friendliness:** Developments in software will continue to make microcomputers increasingly "user-friendly". Experimental software already enables microcomputers to be operated by voice rather then keyboard. Software will be designed for operation in the multitude of languages in the developing world. Future users will not need to learn complicated command structures nor need to know English, French, or Spanish to be able to function on a microcomputer.

- **Data Storage and Memory Capacities:** New developments in data storage and memory hardware will make microcomputers extremely powerful, compact, and reliable. Compact disks can already hold vast amounts of information.

Conclusion

2.97 Microcomputers offer the benefit of tremendous flexibility and adaptability. In size, responsiveness, portability, durability, and reliability, they are well-suited to African needs and conditions. African nations with strong private sectors have taken the lead in introducing microcomputers. Governments have been slower and more cautious in responding to the allure of microcomputers. In terms of individual and institutional capabilities, many African organizations are not yet ready to use microcomputers.

2.98 **The critical time for the introduction of microcomputers in the public sector comes when a government decides that the quality of its services is too poor or the quantity too low.** With that determination, microcomputers can become powerful tools in decision-making systems. Exactly what the capacities of microcomputers will be in a given situation remain unknown until their use is actually underway. If governments are truly committed to rural development, then microcomputer applications that support rural development will come about.

2.99 A very long perspective must be taken on agriculture in sub-Saharan Africa to see beneficial applications of microcomputer technology in rural areas. For the first generation of users, the benefits as well as the perplexities of microcomputer use will be experienced in the national and district capitals of African nations, not in the countryside. In the meantime, it is important for the governments of sub-Saharan Africa to encourage private sector initiatives in microcomputers and to support training for all levels of personnel involved with microcomputer use.

SECTION III
IMPLEMENTATION STRATEGIES

3.1 In Section III the basic principles and concepts designated by the Office of Technology Assessment for the development of low-resource agriculture in sub-Saharan Africa are applied to the communication/information technologies discussed in Section II. The focus is on the design and development of rural communication systems that will enable the remote and isolated populations of Africa to be included in national development for the improvement of their own welfare and income.

3.2 Two sub-sections highlight processes that are essential for the development of effective communication systems. First, **the planning requirements** for new technological systems are discussed, and then the process of **development communication** is explained. The first deals with issues at the macro-level, the second at the micro-level.

APPLICATION OF OTA'S PRINCIPLES AND CONCEPTS:

Communication and Information Technology to Support Low-Resource Agriculture

Principle A: Systems Approach

To be Done	How	Who	Constraints
o Base planning of communication and information systems for rural areas on needs of users.	o Conduct needs assessments of farmers, extension agents, project managers.	o Ministries of Agriculture, Information, and Telecommunications.	o Lack of national commitment to rural communication systems- not a high priority for use of foreign exchange.
o Integrate planning of technology and of applications.	o Include service providers and users in planning from start of process.	o Ministries - same as above.	o Lack of effective mechanism for inter-ministry coordination.
o Assess impact of new technology on environment - natural, cultural and institutional.	o Conduct feasibility and impact studies.	o Ministries - same as above. o Universities.	o Lack of expertise in conducting needs assessments or impact and feasibility studies.
o Educate development ministries about potential applications of communications and information technology.	o Conduct international and regional seminars and training programs.	o Donor agencies o Regional associations - URTNA, UAPT, etc. o International associations - UNESCO, FAO, etc. o IARC's.	o Inadequacy of basic communications infrastructure.

Principle B: Enchance Farmers' Positive Linkages

To be Done	How	Who	Constraints
o Base communication strategies on existing networks of communication.	o Conduct behavioral research of farmers.	o Ministry of Agriculture.	o Lack of national commitment to rural communications system.
	o Map agricultural communications - positive linkages and missing links.	o Universities.	
o Make use of simplest possible technology to facilitate communication and transfer of information.	o Provide public telephone services for communication.	o Ministry of Telecommunications.	o Technical planning focuses too strongly on equipment, instead of on users and their needs.
	o Make use of radio for transfer of information.	o Ministry of Information.	
o Encourage uses of new systems.	o Provide training to all users of new technological systems.	o Ministries. o Donor agencies.	o Lack of expertise in conducting behavorial research.
o Ensure reliability of new technical systems.	o Design new technical systems to endure in local conditions.	o Ministries. o Manufacturers and suppliers of equipment.	o No perceived market for Africa-conditioned equipment.

Principle C: Minimize Farmer Risk

To be Done	How	Who	Constraints
o Integrate communication/information strategies with other inputs vital to agriculture - credit, seeds, fertilizer.	o Plan communication systems for rural areas in conjunction with other development activities in same location.	o Ministries. o IARC's.	o Lack of coordination among ministries and organizations implementing development activities.
o Provide support system for new technologies and information bases.	o Assess support needs and provide system for repair and servicing of system.	o Private sector.	o Poor allocation of communication resources among users.
o Provide information appropriate for use by farmers in target area.	o Guarantee that resources are available for local populations to implement activities promoted through communication/information efforts. o Assess farmers' constraints in adopting new practices.	o Ministries.	o Lack of supporting infrastructure - banks, merchants, etc.

Principle D1: Base Development Efforts on Local Resources

To be Done	How	Who	Constraints
o Know the farmer and the institutions that impact on the farmer.	o Research.	o Ministries. o Universities.	o Lack of respect for local strategies and adaptations.
o Include African scientists and researchers in international dialogue.	o Design information systems; compile database for African agriculture and African agriculturists.	o International development organizations - FAO, IDRC, etc. o IARC's.	o Lack of expertise in in conducting anthropological research.
o Design locale - specific programming.	o Train African researchers to participate in international information systems, such as AGRIS.		o Lack of reliable databases for African agriculture. o Personnel not trained in analysis of data.

Principle D2: Use Multiple Channels

To be Done	How	Who	Constraints
o Design communication/information strategies that utilize variety of approaches and media.	o Test impact of messages and media.	o Development Ministries and Communication/Information Ministries.	o Lack of expertise in conducting formative evaluation, message testing.
o Choose communication technology and channel appropriate for task.	o Test availability of media.	o Project teams.	o Lack of resources to carry out cyclical process of evaluation, monitoring, and adjustment.
o Ensure that all communication/information efforts support each other.	o Assess audience access to media and audience reaction to media.		
o Structure feedback opportunities into basic design of communication strategy.	o Coordinate mass media with interpersonal communication to obtain feedback.		o Centralized, controlled planning and implementation; government fear of feedback.
o Structure monitoring and adjustment into design.	o Adjust communication/information strategies based on results of testing, formative evaluation, and monitoring.		

Principle E and F: **Assess Differential Impact of Development Strategies on Heterogeneous Population: Gender, Age, Ethnic Group, Economic Status**

To be Done	How	Who	Constraints
Target audiences/end-users by sex and age group according to agricultural role and resource base.	o Conduct research on patterns of communication and differential access to and control over resources.	o Ministries. o Private Voluntary Organizations.	o Lack of women in official positions - gender gap between service providers and farmers.
Assess access of each sub-group to communication/information resources.	o Base applications and programming on needs of targeted sub-groups.		o Broadcasters lack of knowledge of rural conditions - complexity and diversity of rural population.
Develop strategies to increase access of isolated sub-groups - i.e., women, nomads, herders - to media.	o Assess impact of new technology on pre-existing balance of power - at farm level or institutional level.		o Inadequate information bases. o Resistance by power-holders to change.
Develop applications based on needs of each sub-group.			

Principle G: Manage for Sustainability

To be Done	How	Who	Constraints
o Social: Assess impact of new technologies on balance of power and allocation of jobs.	o Include all groups in planning and implementation. o Retrain workers.	o Ministries. o Donor agencies.	o Resistance to change. o Resistance to sharing resources.
o Environmental: Design system especially adapted to rigors of African climate and power sources.	o Use alternate souces of power, low-energy consumption equipment. o Protect equipment from heat and humidity.	o Engineers and technicians.	o No local development capacity for equipment. o No market demand for tropical equipment.
o Institutional: Assess impact on balance of power. Choose appropriate tasks for computerization.	o Design new technological systems to complete tasks of high priority.	o Ministries.	o Resistance to change. o Desire for prestige.
o Financial: Budget for ongoing recurrent costs.	o Include funding for maintenance, training, applications development, upgrading of equipment.	o Ministries.	o Not a high priority item when competing for scarce financial resources.

Principle H: Local Participation

To be Done	How	Who	Constraints
o Planning of System: Include all involved ministries from start of process.	o Have all ministries represented on planning team; obtain financial and personnel commmitment.	o Ministries.	o Lack of integrated planning systems approach.
o Include all users in system design - whether the Ministry of Agriculture or a farmers' cooperative.	o Test all applications in the field.	o Ministries.	o Lack of testing. o Lack of training resources.
o In design of applications, include extension service and farmers.	o Test ability of broadcasters or extension agents to deliver information.	o Ministries.	
o In applications, test all messages with targeted farmer-audience.	o Provide training for all personnel functions - engineers, technicians, broadcasters, extension agents, etc.	o Training Centers - national, regional, and international.	

PLANNING REQUIREMENTS

3.3 Briefly outlined below are the major planning requirements for the development of integrated rural communication systems in Africa. Such planning entails questions of hardware and software, engineering and programming, cost and content, quality of sound and of message. How can policy makers and systems designers structure rural communications to include, rather than further isolate, Africa's rural populations?

3.4 The points discussed here are general in nature and relate broadly to planning for all levels of communication and information technology transfer. Specific factors that pertain to each technology alone were discussed in Section II.

Political Will: National Commitment to Rural Development

3.5 Major communication efforts for rural areas demand large commitments of time, funding, and manpower. Strong political backing at the highest levels of government is therefore critical for the successful planning and implementation of rural development programs that include communication infrastructure and programming.

Institutional Participants in Planning and Developing Rural Communication Systems

3.6 The planning and development of rural communication systems requires the participation of institutions at the international, regional, and national levels. The following figure depicts the kinds of institutions that should be involved from the beginning of any rural communication initiative. Traditionally planners have focused first on equipment requirements, and only after equipment has been procured and installed have planners considered the development of applications. It is imperative for the user agencies - Ministries of Agriculture, Health, and Education, etc. - to be involved as equal partners in the development of rural communications. (Figures in Appendix E further elaborate on the range of international/regional institutions and information centers in Africa that would be potential users of communication services for rural development.)

Figure 1

SELECTED INSTITUTIONS INVOLVED IN PLANNING AND DEVELOPING RURAL COMMUNICATION SERVICES*

Level	Providers of Communication Services and Assistance	Users of Communication Services
International	Donor Agencies and Banks Equipment Manufacturers and Suppliers Intergovernmental Bureau for Informatics (IBI) International Telecommunications Satellite Organization (INTELSAT) International Telecommunications Union (ITU) Centre for Telecommunications Development United Nations Educational, Scientific and Cultural Organization (UNESCO) International Programme for the Development of Communications (IPDC) United Nations Development Program (UNDP)	Multi-Lateral and Bilateral Donor Agencies* Private Voluntary Organizations (PVO's) Development Organizations*
Regional	Economic Commission for Africa (ECA) Pan African Telecommunication Union (PATU) Union of African Posts and Telecommunication (UAPT) Union of African Radio and Television National Agencies (URTNA)	Pan African News Agency (PANA) Pan African Development Information Service (PADIS) International Agricultural Research Centers (IARC's)*
National	Ministries of Posts and Telecommunications Ministries of Information Broadcasting Services	Ministries of Agriculture, Health, and Education National Information and Research Centers* Universities

* See Figures in Appendix E for more complete listings of international, regional, and national institutions.

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Time Frame

3.7 Communication systems that involve complex new technologies require long lead times to allow for negotiation, planning, budgeting and the design, trial, and final development of systems, including equipment and program components. Even before major communication initiatives are undertaken, African leaders and policymakers must be introduced to the benefits and applications of modern rural communication systems. Service providers may not understand the potential economic benefits of investment in rural communication, and service users may not understand the potential uses of communication services on behalf of rural development. Rural communication systems require collaboration among agencies which lack precedent for such cooperation. Therefore initial system development must be viewed in a time frame of at least 5-10 years.

Sources of Funding

3.8 While telecommunications do generate income, rural satellite-based communication systems will not be self-supporting at their inception. Their purpose is not revenue generation; rather the purpose is the stimulation of development. Large commitments of funding will be required from international and national sources over long periods of time. Negotiation is required to assure funding commitment and regulation of the fees and tariffs charged to user agencies.

Necessary Budget Categories

3.9 Modern communication projects have tended to stress hardware costs. It is essential that budgets for rural communication systems allow ample funding on a recurrent basis for applications development, management, personnel training, and system maintenance. Too often projects have failed due to the lack of funding for maintaining technical equipment and for assuring the presence of skilled personnel for the management, use, and upkeep of the system.

Joint Development of System by Service Providers and Services Users

3.10 Not only do rural communication programs require strong national backing, they also depend on the commitment of the service providers (Ministries of

Posts and Telecommunications, in particular) and service users (Ministries of Agriculture, Education, and Health) to learn from each other and work together through each stage of program development. Such collaboration is essential in order to maximize potential services related to rural development while simultaneously minimizing costs. Service providers are generally oriented to urban populations and do not understand rural needs; service users are not proficient in the use of high technology. They must forge a strong working relationship that will survive changes in political leadership and the transition from demonstration project to operational service.

Assessment of Rural Communication Needs and Specification of Priorities

3.11 Service providers and users will need to cooperate in conducting rural needs assessments of the communication and information services that will support low-resource agricultural development. The service requirements and cultural patterns of rural users will form the basis for the design of the communication system. Requirements will vary throughout the regions of Africa according to topography, climate, population density and distribution, educational level, stage of economic development, and quality of existing infrastructure. This information will determine the design of services and their order of priority.

System Design: Hardware and Software Appropriate for Rural Conditions

3.12 System design, done jointly by the provider and the user agencies, must be based firmly on the reality of rural conditions throughout Africa - whether hot and humid or dry and arid, including seasonal variations. Power sources are problematic, and air conditioning cannot be guaranteed. The history of development in Africa is full of abandoned efforts due to equipment breakdown.

3.13 The International Telecommunication Union (ITU) has set specific criteria for the technical performance of physical components of telecommunication systems, as well as for the training needed to assure maintenance and operation capability among local staff. Further criteria relate to the choice of project sites and specifications for the development of software. Rural communication systems which incorporate telephone services, broadcasting, teleconferencing, and facsimile are most effective in areas which are already active sites of development projects. There the added communication/information capability yields the greatest return on investment, because ongoing projects can readily make use of the new services.

3.14 . Vendors of hardware and developers of software need to realize the potential of Africa as a market for communication and information technologies. African nations and donor agencies must work together to persuade the manufacturers of hardware and software to develop components suitable to African conditions in terms of physical durability, power requirements, and software applicability.

Personnel Requirements

3.15 Africa lacks trained personnel of all levels and types for the planning and operation of rural communication and information systems. Trained personnel are needed in the technical, applications, and management areas. One of the greatest constraints on the development of modern communication systems is the lack of resources to train personnel as planners, engineers, technicians, rural broadcasters for radio and television, development communicators, information analysts, and program administrators.

Technology Development and Obsolescence

3.16 All three of the technologies examined in this paper are undergoing very rapid change in an international environment which lacks manufacturing standards as well as guidelines for the sharing of information on technical developments. International market forces based in the developed world drive the design and production of equipment. In the area of microcomputers, this results in a lack of equipment and programming compatability; in telecommunications in the changeover from analog to digital transmission of information, and in broadcasting in the conflicting uses of frequencies. Planners in Africa must keep abreast of new technological developments, so that African systems are developed that will be robust, long-lasting, and interconnectable.

DEVELOPMENT COMMUNICATION PROCESS

3.17 What is the relationship between development and communication? Communication - the media and the message - is an integral component of any development effort. Extension agents, bankers, researchers, and government officials all need information from farmers to plan agricultural programs, and farmers in turn need information to improve their own welfare. Often, however, these brokers of information are unable to communicate effectively with farmers, especially low-resource farmers. The development communication process encompasses a cyclical process of research, design, testing, implementation, monitoring, and evaluation.

3.18 Communication efforts must be incorporated into agricultural development activities. Agricultural officials - from national decision-makers to field workers - must value the communications components of projects and understand the capabilities of the different media, both traditional and modern. Training on the appropriate applications of new technologies should be ongoing. The costs of training and the costs inherent in the development communication process - research, testing, and production of materials - must be seen as integral to agricultural development, not as discretionary items.

Understanding the Farmer

3.19 At the heart of the development communication process is the need to understand the target audience - in the case of low-resource agriculture, the small farmers of Africa. Who are they? Are they settled or nomadic? What are their goals? What are the agricultural tasks of women, of men? What resources do they have access to? What are their languages?

3.20 Efforts to improve low-resource agriculture must be targeted to specific groups of farmers who function in specific ecological, economic, and cultural conditions. Furthermore, planners must understand the communication constraints of targeted farmers. Are they literate? Do they have access to radio, television, or telephone? Do they have contact with extension agents or other development workers? What needs for information do they express? To understand farmers, techniques from anthropology, behavioral analysis, and social marketing are useful and form the first stage of research in development communications.

Targeting Areas for Change

3.21 Agricultural communication strategies should be applied to priority areas targeted for change, so that communication efforts complement district or national agricultural programs. Communication efforts succeed only in the presence of other conditions; inputs and resources necessary to implement changes in farm practices must be readily available to farm families as they are learning about new practices.

3.22 Low-resource farmers minimize risk and therefore resist making changes in their agricultural practices. Information and communication services related to agricultural development must fit into a project framework that appears meaningful and promising to the farmer, not simply to the project planner or extension worker.

Designing and Testing Messages

3.23 Once specific agricultural practices have been targeted for change, communication messages are designed. Testing is imperative in order to determine how participating farmers perceive and receive the draft messages. Written and spoken words as well as pictorial images must communicate clear messages to farm families. Messages must convey information that does not conflict with conditions in the farmers' locale.

3.24 The design of messages incorporates the specification of behavioral objectives related to targeted agricultural practices. Message research allows project planners and agricultural workers to judge the match between the message sent and the message received, as well as concomitant changes in farmer behavior.

Developing the Communication Strategy

3.25 No single form of communication - teleconferencing, radio broadcast, print, or interpersonal - is diverse or flexible enough to reach and instruct the entire group of farmers participating in a given agricultural project. Development of the communication strategy includes testing the viability of different media to reach the farmers and choosing the communication methods (media and messages) to use throughout a project. Different communication activities utilizing different communication channels should complement each other, strengthening project impact and reinforcing new farmer behaviors.

Project Implementation

3.26 Communication research activities prior to project implementation include farmer research, message research, and communication channel research. Once the research is complete and the overall communication strategy in place, communication activities are ready for implementation in support of the other project components.

3.27 Implementation includes the vital functions of inter-organizational coordination and resource allocation. Especially in agricultural projects, inputs and information must be closely tied to seasonal changes and fluctuations in climatic and economic structures. The management structure of a project must have the flexibility and creativity to foresee and react to changing conditions.

Evaluation and Monitoring

3.28 Research is continuous throughout the development communication process. During implementation, the results of all communication efforts are tracked through a process of formative evaluation, and changes are made in the use of media or the content of messages as necessary. Feedback from farmers is a critical component in effective communications. Information in an of itself has no value except as it is perceived and used by the farmers; their participation is the measure of project success or failure.

SECTION IV

POLICY RECOMMENDATIONS

4.1 As a world leader in the communications and information revolution, the United States has a unique responsibility to share the benefits of this revolution with the developing world. **What policies can the United States adopt to encourge the development of communication and information systems in sub-Saharan Africa that will effectively support rural development in general and agriculture specifically?** Recommendations made here are based on the applications of communication/information technology to agriculture already discussed in Section II.

4.2 Over the past decade the U.S. Agency for International Development (USAID) has pioneered much of the research on appropriate communication/information technology and its applications in the developing world. USAID's programs in radio learning, rural satellite communications, telecommunications training, and agricultural communication have demonstrated the viability of using these new technologies in developing countries. The development organizations and universities that have participated in these programs represent a broad base of experience and expertise. **It is imperative that Congress continue to support USAID's programs in development communications.**

4.3 While USAID should continue its communication programs, it should also move to consolidate the knowledge in communications gained over the past decade from all sectors (health, education, as well as agriculture) and from all continents (Asia, Latin America, as well as Africa). **USAID should focus this learning on the development of applications for Africa, specifically for low-resource agriculture.** Communications efforts should be expanded by mandating a communication/information component in every new rural development project, especially in agricultural projects.

4.4 Many efforts are underway throughout the world to study and stimulate communications development in Africa - from the United Nations agencies such as ITU, UNESCO, and UNDP to regional organizations such as PATU, UAPT, and URTNA. Donor agencies in many developed nations have very active communication programs, such as the IDRC in Canada. **The U.S. government needs to act in partnership with the international, regional, and national organizations that have communications programs.** The U.S. government should work with and through the appropriate international and regional organizations to promote the building of cooperation and establishing of economies of scale. In particular, the United States should support the recommendations of the Maitland Commission and encourage a strong focus on Africa in the work of the newly-established Center for Telecommunications Development in Geneva. Through its support of the International Agricultural Research Centers, the United States can advocate the development of strong linkages between researchers, extension agents, and farmers.

4.5 **The U.S. government should also seek to channel and mobilize the expertise of the U.S. private sector for application in meeting the communication needs of developing nations.** Major barriers still do exist to the participation of U.S. communications firms in Third World development. The U.S. government should take action to lower barriers in the areas of financing, trade policy, and export review processes.

- **Financing:** If U.S. firms are to be competetive in the international marketplace, they must be able to offer financing packages which are attractive to developing nations. Japanese and European communication companies are tied closely to their governments and are able to offer much lower financial terms to developing nations. The U.S. government, development banks, and U.S. firms must cooperate in the crafting of financial packages. The U.S. government should encourage its international trade and assistance programs which focus on securing private sector involvement (for example, the Overseas Private Investment Corporation, the Agency for International Development's Private Enterprise Bureau, the Trade and Development Program of the International Development Cooperation Agency, and the Export-Import Bank) to concentrate more of their resources in the communications sector.

- **Trade Policy:** The U.S. government and the U.S. private sector should continue negotiating efforts with OECD countries to liberalize their telecommunication policies. Most OECD countries have restrictions on the import of U.S. communications equipment, and if U.S. firms are to undertake the manufacture of equipment at overseas standards, they must have sufficiently large markets open to them.

- **Export Review Process:** The Department of Defense requires a lengthy review process for export of communication and information equipment which it considers sensitive. The review process must be streamlined, so that U.S. firms can confidently guarantee delivery of equipment to developing nations in a timely manner.

4.5.1 The U.S. government should support and encourage all efforts at dialogue among government agencies, private sector firms, and banks about the importance of communications development in the Third World. In this regard, the U.S. government can help educate and sensitize U.S. firms to their responsibilities when working with or in developing nations. These responsibilities include employment of host country citizens at all levels of the firm's operations and training for employees in technical and managerial fields; use of technology appropriate to the local environment and research and development of equipment adapted to local requirements; use of locally-produced equipment and locally-available resources. An important example of government/industry cooperation is provided by the U.S. Telecommunications Training Institute; the Institute pools the resources and expertise of the government and private industry to offer training to personnel from developing countries.[8]

4.6 By expanding its support for USAID communication programs and by creating stronger partnerships with international and regional organizations on the one hand and with the U.S. private sector on the other, **the U.S. government can bring very significant resources to bear on the following areas which are critical to the development of communication/information systems in sub-Saharan African.**

Leadership

4.7 Critical to the development of national communication systems is the commitment of African leaders to include rural areas in national communication networks. This involves clear recognition and understanding of the role communication can play in stimulating economic growth, even in or especially in remote areas. **The leaders of developing nations must make communication systems an important national priority and must communicate this sense of priority and urgency to international donor agencies.**

4.8 **The U.S. government can act as an important catalyst in educating the leaders and policymakers of sub-Saharan Africa to the benefits of investment in communications and the dangers of neglect.** The U.S. government through its international visitor and training programs introduces leaders from around the world to modern communication/information technologies and their applications. The U.S. government should also enhance African leadership development and learning through promoting regional dialogue and exchange.

Management

4.9 While pilot projects have demonstrated that advanced communication and information technologies can be transferred successfully to developing nations, technicians trained, and applications designed, what is still lacking are the management systems for sustaining new technical systems and implementing effective applications. **Not only should the U.S. government encourage training and education in specific**

technologies and their applications, it should encourage and support training for the management capacities needed to run rural communication systems on a long-term basis.

Human Resources

4.10 The U.S. government should support the "learning" efforts of developing nations at several levels. The U.S. needs to demonstrate to African leaders and policy-makers what modern communication/information systems are and what meaning they can hold for Third World development. **The U.S. needs to support the education and training of all levels of personnel involved in designing, maintaining, managing, and using these new systems.** Except at the most advanced levels, training should be conducted in Africa at designated regional or national centers, so that learners develop their skills and knowledge in the environment in which they will have to function. Trainers from the United States or other developed countries should be adept at working in African contexts.

Equipment

4.11 The technical know-how exists to develop equipment especially suited to African climates. Such equipment is not widely produced, however, because of a lack of market demand. **The U.S. government should work with African nations to assist them in formulating and articulating their technical needs on a regional basis, and the U.S. government should encourage U.S. private sector companies to meet the challenges of developing simple and rugged equipment for use in Africa.** The U.S. government should also explore creative ways to reduce the unit price of equipment - e.g., through bulk orders - and to facilitate the financing of communication efforts - e.g., through regional sharing of satellite services or through "piggybacking" rural applications to commercial ventures.

Conclusion

4.12 In conclusion, **three criteria emerge for the U.S. government to use in selecting the communication efforts it will support and the ways in which it will express such support.**

- **Luxury Versus Necessity:** Does a particular application represent a luxury in the context of African poverty - e.g., the use of microcomputers in primary education? Or does it represent an investment that will improve the welfare and income of a significant proportion of the population?

- **Institutionalization:** Is support committed over a sufficient length of time for a project not only to be set up, but also tested, revised, managed, and established as a regular operation? Thus far, many projects have been demonstrations alone and have failed to make the transition to operations. Training and education of personnel take time; repair and maintenance of equipment take time; applications development and testing take time. This points to the need for smaller, more specific, and better-designed projects as part of on-going, long-term program commitments that span national boundaries in Africa, as well as changes in political administration in the United States.

- **Development Effect:** What effect on development goals and problems will the application have? Does the application focus on internal institutional efficiencies alone - e.g., payroll - or will it have a significant impact on the delivery of services to the rural populations of sub-Saharan Africa?

END NOTES

1. For further information on the use of solar power in developing countries, see Louis Rosenblum et al., "Photovoltaic Power Systems for Rural Areas of Developing Countries," NASA Technical Memorandum 79097, Technical Paper presented at the Interregional Symposium on Solar Energy for Development (Tokyo, Japan, February 1979), pp. 2, 27. For further information on UNESCO's radio program, see UNESCO, "Radio, TV, Press," Communication Sector, Division of Development of Means of Communication (Paris, France, March 1985), pp. 1-3, 6; Academy for Educational Development, "A Worldwide Radio Receiver Population Analysis," study prepared for the United States Information Agency (Washington, D.C., May 1986), pp. 72-74.

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APPENDIX A

Radio, Television, and Telephone Distribution Worldwide

TABLE 3

6.8 Number of radio broadcasting transmitters

CONTINENTS, MAJOR AREAS AND GROUPS OF COUNTRIES CONTINENTS, GRANDES REGIONS ET GROUPES DE PAYS CONTINENTES, GRANDES REGIONES Y GRUPOS DE PAISES	TOTAL NUMBER OF RADIO BROADCASTING TRANSMITTERS NOMBRE TOTAL D'EMETTEURS DE RADIODIFFUSION SONORE NUMERO TOTAL DE TRANSMISORES DE RADIODIFUSION SONORA				
	1965	1970	1975	1980	1981
WORLD TOTAL	16 400	22 100	25 800	28 850	29 700
AFRICA	500	680	730	900	950
AMERICA	9 640	10 910	12 730	14 670	15 200
ASIA	1 390	1 930	2 730	2 950	3 000
EUROPE (INCLUDING U.S.S.R.)	4 580	8 270	9 280	9 900	10 100
OCEANIA	290	310	330	430	450
DEVELOPED COUNTRIES	11 670	16 200	19 100	21 400	22 000
DEVELOPING COUNTRIES	4 730	5 900	6 700	7 450	7 700
AFRICA (EXCLUDING ARAB STATES)	400	580	580	680	720
ASIA (EXCLUDING ARAB STATES)	1 330	1 830	2 630	2 810	2 850
ARAB STATES	180	220	250	380	380
NORTHERN AMERICA	6 170	6 770	8 530	10 100	10 400
LATIN AMERICA	3 470	4 140	4 200	4 570	4 800

TABLE 4

6.9 Number of radio broadcasting receivers and receivers per 1,000 inhabitants

CONTINENTS, MAJOR AREAS AND GROUPS OF COUNTRIES CONTINENTS, GRANDES REGIONS ET GROUPES DE PAYS CONTINENTES, GRANDES REGIONES Y GRUPOS DE PAISES	NUMBER OF RADIO BROADCASTING RECEIVERS NOMBRE DE RECEPTEURS DE RADIODIFFUSION SONORE NUMERO DE RECEPTORES DE RADIODIFUSION SONORA TOTAL (MILLIONS/MILLONES)					PER 1,000 INHABITANTS POUR 1 000 HABITANTS POR 1 000 HABITANTES				
	1965	1970	1975	1980	1982	1965	1970	1975	1980	1982
WORLD TOTAL	536	684	961	1 251	1 352	159	186	238	282	294
AFRICA	10	16	28	42	50	32	45	69	91	101
AMERICA	285	357	505	603	637	617	701	903	986	1 004
ASIA	53	70	138	246	281	28	30	60	95	105
EUROPE (INCLUDING U.S.S.R.)	184	233	277	342	362	272	331	380	456	478
OCEANIA	3	8	13	19	22	171	421	619	822	917
DEVELOPED COUNTRIES	460	572	770	943	988	449	532	686	810	837
DEVELOPING COUNTRIES	75	112	191	307	366	32	43	66	94	107
AFRICA (EXCLUDING ARAB STATES)	6	8	17	27	33	26	30	56	76	87
ASIA (EXCLUDING ARAB STATES)	51	68	132	235	270	27	33	58	93	103
ARAB STATES	6	10	17	25	29	56	81	121	153	167
NORTHERN AMERICA	251	306	424	496	514	1 173	1 364	1 797	1 992	2 032
LATIN AMERICA	34	51	81	107	124	137	180	251	295	324

Source: UNESCO, Statistical Yearbook 1984, pp.VI-19,20.

TABLE 5

6.10 Number of television transmitters

CONTINENTS, MAJOR AREAS AND GROUPS OF COUNTRIES CONTINENTS, GRANDES REGIONS ET GROUPES DE PAYS CONTINENTES, GRANDES REGIONES Y GRUPOS DE PAISES	NUMBER OF REGULAR TELEVISION TRANSMITTERS NOMBRE D'EMETTEURS DE TELEVISION FONCTIONNANT REGULIEREMENT NUMERO DE TRANSMISORES DE TELEVISION QUE FUNCIONAN REGULARMENTE				
	1965	1970	1975	1980	1981
WORLD TOTAL	8 550	17 700	29 000	38 800	41 100
AFRICA	100	140	230	270	290
AMERICA	3 070	4 310	5 000	5 400	5 700
ASIA	1 100	3 780	6 700	11 600	12 800
EUROPE (INCLUDING U.S.S.R.)	4 200	9 240	16 700	21 000	21 800
OCEANIA	80	230	370	500	500
DEVELOPED COUNTRIES	8 100	16 900	27 580	36 800	38 800
DEVELOPING COUNTRIES	460	800	1 420	2 000	2 300
AFRICA (EXCLUDING ARAB STATES)	55	70	120	160	160
ASIA (EXCLUDING ARAB STATES)	1 070	3 730	6 630	11 100	12 600
ARAB STATES	75	120	180	310	330
NORTHERN AMERICA	2 820	3 880	4 380	4 550	4 700
LATIN AMERICA	250	460	840	850	1 000

TABLE 6

6.11 Number of television receivers and receivers per 1,000 inhabitants

CONTINENTS, MAJOR AREAS AND GROUPS OF COUNTRIES CONTINENTS, GRANDES REGIONS ET GROUPES DE PAYS CONTINENTES, GRANDES REGIONES Y GRUPOS DE PAISES	NUMBER OF TELEVISION RECEIVERS NOMBRE DE RECEPTEURS DE TELEVISION NUMERO DE RECEPTORES DE TELEVISION TOTAL (MILLIONS/MILLONES)					PER 1,000 INHABITANTS POUR 1 000 HABITANTS POR 1 000 HABITANTES				
	1965	1970	1975	1980	1982	1965	1970	1975	1980	1982
WORLD TOTAL	186	278	394	530	564	56	76	98	120	123
AFRICA	0.6	1.2	2.5	7.2	8.5	1.9	3.4	6.2	15	17
AMERICA	84	109	160	192	204	182	214	286	314	321
ASIA	24	39	57	96	108	13	19	25	37	39
EUROPE (INCLUDING U.S.S.R.)	75	125	169	229	239	111	178	232	306	316
OCEANIA	2.4	3.5	5.5	6.5	7.5	137	184	262	285	321
DEVELOPED COUNTRIES	175	255	363	454	478	171	237	315	390	405
DEVELOPING COUNTRIES	11	23	41	76	86	4.7	9	14	23	25
AFRICA (EXCLUDING ARAB STATES)	0.1	0.3	0.6	3.5	3.8	0.4	1.1	2.0	9.9	10
ASIA (EXCLUDING ARAB STATES)	24	38	56	90	100	13	18	25	35	38
ARAB STATES	0.9	1.9	3.4	8.4	10.2	8.4	15	24	51	59
NORTHERN AMERICA	76	92	133	153	161	385	407	564	617	638
LATIN AMERICA	8	17	27	39	43	32	60	84	107	111

Source: UNESCO, Statistical Yearbook 1984, p.VI-21,22.

TABLE 7

WORLD RADIO AND TELEVISION RECEIVERS

	Number of radio sets per 100 population	Number of television sets per 100 population
Africa – South of Sahara		
Angola	7	*
Benin	8	*
Botswana	9	*
Burkina Faso	4	*
Burundi	5	-
Cameroon	14	-
Cape Verde	16	-
Central African Republic	6	*
Chad	3	-
Comoro Islands	13	-
Congo	13	*
Djibouti	8	3
Equatorial Guinea	23	1
Ethiopia	4	*
Gabon	10	2
Gambia	17	-
Ghana	16	1
Guinea-Bissau	4	-
Guinea	5	*
Ivory Coast	11	5
Kenya	11	1
Lesotho	7	-
Liberia	23	2
Madagascar	21	1
Malawi	9	-
Mali	5	*
Mauritania	14	-
Mauritius	23	10
Mozambique	5	*
Niger	5	*
Nigeria	17	7
Réunion	23	15
Rwanda	5	-
St. Helena, Ascension and Tristan da Cunha	33	-
São Tomé and Principe	23	-
Senegal	10	1
Seychelles	43	1
Sierra Leone	20	1
Somalia	5	*
South Africa	33	11
Swaziland	15	1
Tanzania	10	*
Togo	14	1
Uganda	10	1
Zaire	10	*
Zambia	13	3
Zimbabwe	13	3
Asia, Australasia and Oceania		
Afghanistan	10	1
Australia	114	42
Bangladesh	4	*
Bhutan	1	-
Brunei	24	14
Burma	8	*
Cook Islands and Niue	52	-
China	10	3
Fiji	50	-
French Polynesia	50	13
Guam	132	70
Hong Kong	61	23
India	6	*
Indonesia	16	2
Japan	83	58
Kampuchea	10	1
Kiribati	20	-
Korea, North	11	1
Korea, South	45	23
Laos	10	*
Macau	30	2
Malaysia	18	12
Maldives	9	1
Micronesia	52	6
Mongolia	14	4
Nauru	63	-
Nepal	3	-
New Caledonia	34	27
New Zealand	90	34
Pakistan	9	2
Papua New Guinea	6	-
Philippines	14	3
Samoa, East	114	43
Samoa, West	38	3
Singapore	39	30
Solomon Islands	10	-
Sri Lanka	17	1
Taiwan	28	26
Thailand	16	5
Tonga	40	-
Tuvalu	25	-
Vanuatu	24	-
Vietnam	10	3
Americas		
Argentina	66	23
Bahamas	73	33
Barbados	83	25
Belize	63	9
Bermuda	160	71
Bolivia	25	7
Brazil	35	19
Canada	121	52
Chile	32	15
Colombia	21	10
Costa Rica	25	12
Cuba	33	15
Dominican Republic	15	8
Ecuador	32	7
El Salvador	35	8
Falkland Islands	50	-
French Guiana, Martinique and Guadeloupe	39	17
Guatemala	23	5
Guyana	30	-
Haiti	15	*
Honduras	16	2
Jamaica	40	9
Leeward Islands	35	18
Mexico	33	11
Netherlands Antilles	71	18
Nicaragua	28	6
Panama	45	18
Paraguay	19	3
Peru	19	10
Puerto Rico	66	24
Surinam	53	13
Trinidad and Tobago	50	27
Turks and Caicos Islands	63	-
Uruguay	60	20
USA	213	72
Venezuela	40	14
Virgin Islands	90	60
Windward Islands	44	3
Middle East and North Africa		
Algeria	23	*
Bahrain	50	22
Egypt	21	4
Iran	27	8
Iraq	18	6
Israel	40	24
Jordan	25	11
Kuwait	78	47
Lebanon	63	23
Libya	22	7
Morocco	21	6
Oman	25	6
Qatar	38	38
Saudi Arabia	32	21
Sudan	10	1
Syria	23	5
Tunisia	18	9
United Arab Emirates	30	19
Yemen, North	5	*
Yemen, South	23	1
Europe		
Albania	17	*
Andorra	23	13
Austria	60	43
Belgium	76	40
Bulgaria	36	27
Cyprus	62	23
Czechoslovakia	58	33
Denmark	78	40
Finland	66	46
France	87	38
Germany, East	72	43
Germany, West	91	40
Gibraltar	83	30
Greece	53	30
Greenland	38	10
Hungary	70	42
Iceland	63	33
Ireland	55	25
Italy	62	44
Liechtenstein	56	33
Luxembourg	75	38
Malta	50	31
Monaco	93	74
Netherlands	87	43
Norway	72	42
Poland	42	27
Portugal	35	23
Romania	36	22
San Marino	46	33
Spain	45	29
Sweden	120	57
Switzerland	78	47
Turkey	15	10
USSR	36	31
United Kingdom	95	47
Yugoslavia	33	21

Source: *World Radio and Television Receivers*, International Broadcasting and Audience Research, British Broadcasting Corporation, Bush House, Strand, London WC2B 4PH, UK, June 1983.

* less than 0.5.

Source: Graham Mytton, "Audience Research for International Broadcasting," INTERMEDIA, Vol. 14, No. 2, p.39.

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TABLE 8

Table 1-3. *Access to Telephone Services in Large Urban and Nonurban Areas in Selected Countries*

Region and country	*Date (month/ year)*	*Telephones per 100 people*		
		National	*Large urban areas*	*Other areas*
Developed				
United States	1/81	83.73	86.05	81.73
Sweden	1/81	79.60	95.02	71.03
Switzerland	1/81	72.45	84.22	64.93
Canada	1/81	67.11	80.95	57.50
Denmark	1/81	63.61	80.96	52.90
Australia	1/81	52.58	58.53	39.57
Netherlands	1/81	50.89	63.13	45.96
United Kingdom	1/81	49.67	63.23	44.04
Japan	1/81	49.40	57.05	41.83
Germany, Fed. Rep.	1/81	46.31	63.85	39.73
France	1/81	45.08	83.46	40.94
Italy	1/81	33.72	49.07	25.09
Spain	1/81	31.00	57.67	23.93
USSR	1/81	8.89	28.31	6.66
Developing				
Africa				
Mauritius	1/81	4.03	1.94	12.21
Algeria	1/81	2.51	8.30	0.54
Swaziland	1/81	2.20	15.65	0.63
Egypt	1/81	1.21	4.35	0.36
Morocco	1/79	1.13	3.36	0.20
Ivory Coast	1/80	1.11	1.18	0.00
Kenya	1/81	1.24	3.10	0.44
Zambia	1/80	1.07	2.46	0.33
Senegal	1/79	0.79	1.61	0.14
Tanzania	1/81	0.56	3.62	0.21
Sudan	1/81	0.34	1.60	0.04
Ethiopia	1/81	0.28	3.53	0.08
Somalia	1/80	0.20	n.a.	n.a.
Cameroon	1/78	0.19	1.06	0.07
Upper Volta	1/80	0.15	0.90	n.a.
Mali	1/79	0.12	n.a.	n.a.
Burundi	1/79	0.12	n.a.	n.a.
Rwanda	1/79	0.12	0.45	0.06
Asia				
Fiji	1/81	7.26	22.32	4.73
Turkey	1/81	4.21	14.27	1.70
Malaysia	1/81	4.44	14.49	2.20
Syria	1/80	2.68	5.95	0.74
Oman	1/79	1.48	n.a.	n.a.
Papua New Guinea	1/81	1.64	14.60	0.28
Philippines	1/81	1.12	3.09	0.00
Thailand	1/81	1.06	5.67	0.23
Sri Lanka	1/81	0.56	5.29	0.21
India	1/81	0.42	3.20	0.20
Pakistan	1/81	0.44	0.48	0.38
Indonesia	1/80	0.28	1.78	0.09
Bangladesh	1/79	0.13	1.33	0.01
Burma	1/78	0.10	0.10	0.00
Nepal	1/78	0.07	2.78	0.01
Latin America				
Argentina	1/81	10.34	16.11	0.00
Uruguay	1/81	9.90	13.23	5.64
Costa Rica	1/81	10.37	21.02	2.48
Venezuela	1/80	8.56	9.14	7.99
Mexico	1/81	7.54	14.00	2.17
Colombia	1/81	5.98	9.43	2.66
Brazil	1/81	6.26	14.98	2.97
Chile	1/81	5.01	8.10	1.29
Ecuador	1/80	5.98	7.29	0.25
Guatemala	1/81	1.58	3.00	0.00
El Salvador	1/81	1.58	4.32	0.00
Haiti	1/80	0.74	6.00	0.10
Peru	1/81	2.83	18.55	0.00

n.a. Not available.

Sources: American Telephone and Telegraph Corporation, *The World's Telephones* (July 1982, June 1981, August 1980, and December 1978); and World Bank data.

Source: Robert J. Saunders, Jeremy J. Warford, and Bjorn Wellenius, Telecommunications and Economic Development, pp. 8-9.

FIGURE 2

COMMUNICATIONS EQUIPMENT, FACILITIES, AND TRAINING IN AFRICAN COUNTRIES

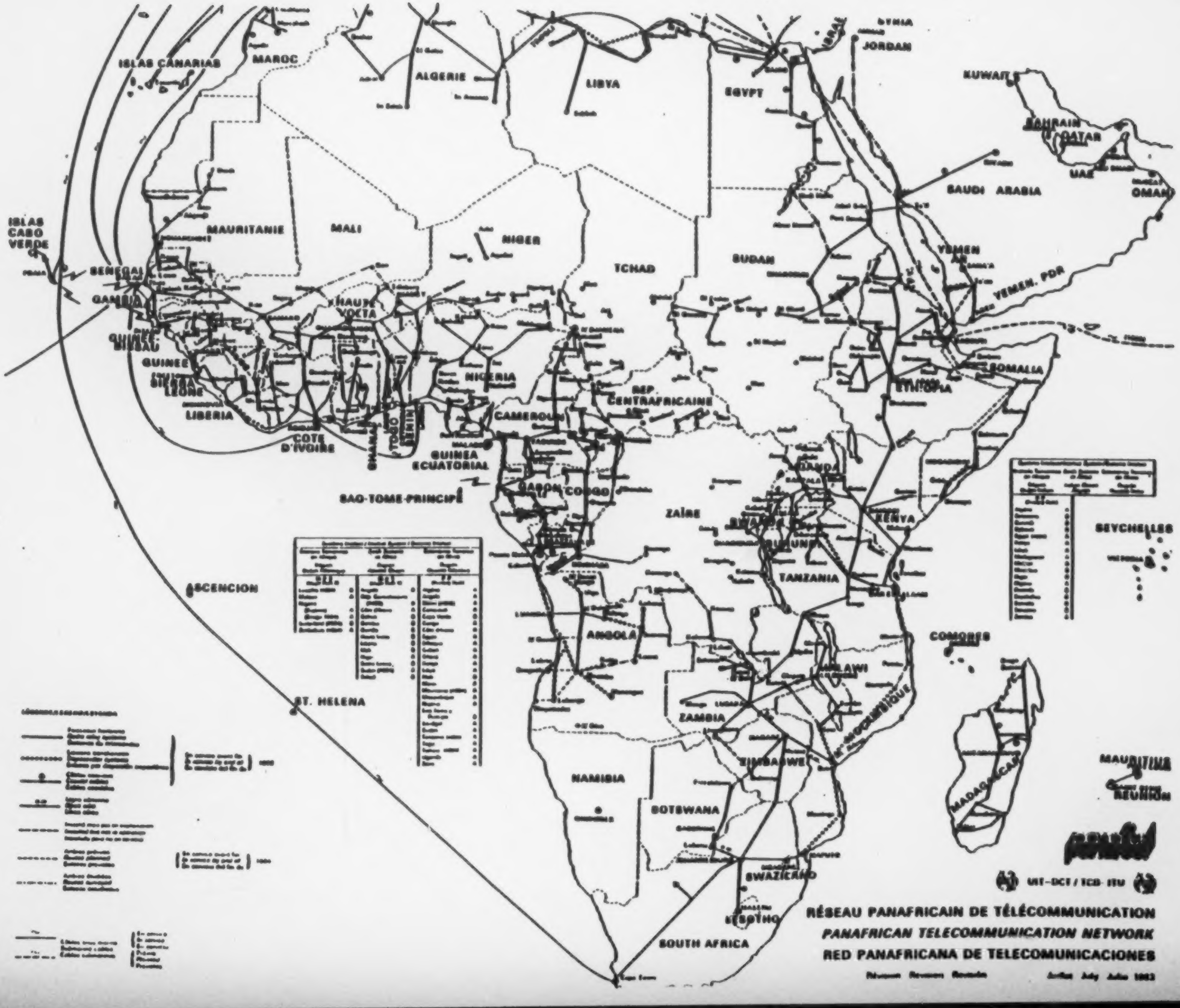
*Currently under planning

	Radio Transmitters	Radio Receivers (AM, FM, SW; 1000's)	Television Stations	Television Receivers (1000's)	Educational/Instructional Television Facilities	Broadcast Training Institutes	Telecommunications Training Facilities (regional)	Telecommunications Training Facilities (national)	Total Number of Telephones (1000's)	Telephones per 100 Population	INTELSAT Earth Stations	DOMSAT Earth Stations (Planned additional stations)
BENIN	4	250	1	12.7			1	1	16.2	0.4	*	
BOTSWANA	7	85.8					1	2	17	1.8	YES	
BURUNDI	7	200						1	4.4	0.1	YES	
CAMEROON	21	1250							30	0.3	YES	(4)
CAPE VERDE	4	41							1.7	0.53	*	
CENTRAL AFRICAN REPUBLIC	2	120	1					1	3.6	0.17	*	
CHAD	5	110						1	2.5	0.05	*	*
COMOROS	3	38							1.8	0.48		
CONGO	4	92	1	4			1	1	13.9	1.1	YES	
DJIBOUTI	3	30	1	10.5				1	5.2	1.4	YES	
ETHIOPIA	13	250	1	35		1	2	2	10.5	0.35	YES	
EQUATORIAL GUINEA	2	100	1	1					1.1	0.3		
GABON	11	96	8	8			1	1	11.6	1.2	YES	
GAMBIA	4	100					1	1	3.9	0.62	YES	
GHANA	22	1500	5	70		5	1	2	48.9	0.5	YES	
GUINEA	8	250	1	7		1	2	2	10.1	0.12	YES	
GUINEA-BISSAU	2	30							2.2	0.38		
IVORY COAST	11	1000	11	540	1		2	2	78.4	1.2	YES	
KENYA	22	1700	4	68		4	1	1	198.3	1.2	YES	
LESOTHO	5	100	*			1		1	5.9	0.43	*	
LIBERIA	11	400	1	21					7.7	0.5	YES	
MADAGASCAR	11	1700	4	71			1	1	37.1	0.4	YES	
MALAWI	14	600				1	1	1	37	0.58	YES	
MALI	10	300						1	8.8	0.12	YES	
MAURITANIA	4	200							5.2	0.2	*	*
MAURITIUS	2	197	4	80				1	37.8	4.0	YES	
NIGER	11	300	9	10	1			1	9.8	0.17	YES	3 (1)
NIGERIA	31	5800	31	435	2	4	3	5	175	0.2	YES	19 (2)
RWANDA	10	300					1	2	4.6	0.09	YES	
SAO TOME AND PRINCIPE	2	23							2.1	2.1	YES	
SENEGAL	17	600	1	30	1	1	1	1	40.2	0.8	YES	
SEYCHELLES	3	25	*						7.1	11.1	YES	
SIERRA LEONE	5	750	2	21				1	16	0.47	YES	
SOMALIA	4	150							7.9	0.16	YES	
SUDAN	9	1330	2	108	1		2	2	68.8	0.36	YES	16
SWAZILAND	25	90	11	6.4				1	12	2.2	*	
TANZANIA	16	2000	2	8				1	101	0.56	YES	
TOGO	11	250	3	10					9.8	0.36	YES	
UGANDA	13	1250	7	75			1	3	62	0.65	YES	
UPPER VOLTA	9	200	1	18.5		1	1	1	11.3	0.16	YES	
ZAIRE	28	2500	2	10	1		1	2	30.3	0.1	YES	13
ZAMBIA	16	500	10	75	1		1	1	196.8	2.89	YES	
ZIMBABWE	24	950	8	96				1	224.5	3.0	*	

Source: Academy for Educational Development, Critical Aspects of the Establishment and Utilization of Satellite Services for Africa, p. 67.

APPENDIX B

Map of Pan African Telecommunication Network



RÉSEAU PANAFRICAIN DE TÉLÉCOMMUNICATION

PANAFRICAN TELECOMMUNICATION NETWORK

RED PANAFRICANA DE TELECOMUNICACIONES

Révision Revision Revisión Juillet July Julio 1983

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APPENDIX C

Project Documentation: Broadcast Radio and Television and Satellite-Based Telecommunication

Projects are listed in the order in which they are cited in the text.

MASAGANA 99
Philippines

TARGET AUDIENCE:	Rice producers in 59 Filipino provinces (approximately 900,000 farmers, according to official estimates)
OBJECTIVES:	To increase rice yields by supplying farmers with credit, loans, agricultural inputs, and timely information on agricultural concepts and practices
MEDIA:	Radio, comics, booklets, flyers, bulletins, vernacular magazines, newspapers, posters, TV, and interpersonal communication
DONORS/SPONSORS:	The National Food and Agriculture Council of the Philippines (an organization composed of 17 Filipino government agencies and banks); the U.S. Agency for International Development; and the International Rice Research Institute
DURATION:	Pilot project and research conducted from 1971 to 1973; implementation phase begun in 1973; ongoing
CONTACTS:	Dr. Arturo Tanco, Secretary of Agriculture, Quezon City, Philippines; Domingo F. Panganiban, Director, National Food and Agriculture Council, Quezon City, Philippines; J.D. Drilon, Jr., Director, Southeast Asian Regional Center for Graduate Study and Research in Agriculture, U.P. at Los Baños, College, Laguna, Philippines; Kenneth F. Smith, OHP USAID Korea, c/o U.S. Embassy, Seoul, APO S.F., CA 96301, USA

DESCRIPTION:

President Ferdinand Marcos launched *Masagana 99* in May of 1973 in a nationally televised ceremony. Calling the project "a program of survival" in the wake of regional flooding in 1972 and of a national drought in 1972/3, Marcos rallied the nation to cooperate in a rice-growing scheme billed as a remedy to a production slump that threatened to deplete the Philippines' foreign exchange and work other economic injuries. The note of urgency reflected the fact that the rice shortage that year had been estimated at 700,000 tons. In terms of the number of farmers involved, the degree of government and private-sector collaboration, geographic sweep, the use of the mass media, reliance upon trained extension agents, the spread of new rice-farming technologies, and gains in rice-yields, the project Marcos announced was the largest and most comprehensive in the nation's history.

Masagana 99 has 11 elements. They include (1) a research-based technology package, (2) a scheme for the production and distribution of seeds, (3) a fertilizer allocation and distribution system, (4) a campaign aimed at controlling pests and plant diseases, (5) a credit scheme, (6) a program for distributing irrigation pumps and otherwise improving irrigation systems, (7) a program for increasing the number and reach of mobile agricultural extension agents, (8) a mass media campaign created to spread information and to educate the public on agricultural concepts and practices, and (9) a system of price supports coupled with procurement and grain-storage programs. The remaining two elements, administrative and cross-sectoral, are a focus on carefully defined target areas and a management unit charged with planning, implementing, and monitoring the overall program.

Radio functions as the mainstay of the mass media component of *Masagana 99*. Its heavy use reflects research findings that radio reaches up to 85 percent of the population and that three out of every four Filipino farmers own a transistor radio. Over 224 radio stations broadcast advice, jingles, and skits on agriculture ten times per broadcast day, while 125 radio stations carry over 50 local agricultural programs. Principal back-up media include instructional comics, booklets and bulletins in the eight major dialects of the country, newspapers (which voluntarily devote ample news space to the project), and instructional promotional posters. TV's role has been limited, consisting primarily of coverage of the project's opening ceremony and of occasional field activities.

The agricultural broadcasters involved in this project serve as more than disc jockeys. They act as information officers in the Provincial Action Committees (the project's basic administrative units), answer queries from listeners, tape interviews with both information suppliers and information users, conduct research related to the broadcasts, and attend community activities related to food production. In addition, they keep daily broadcasting logs, meet weekly with the provincial broadcasting authorities to plan and review programming, and stay abreast of the informational and educational activities of all agricultural and rural development agencies.

In 1977, *Masagana 99's* emphases on realizing higher yields and including increasing numbers of farm families were intensified. Since then, the project has been known as *Masagana 99 + 10*.

RESULTS:

Despite transportation problems, inclement weather, distribution tie-ups, and pest infestations, rice yields in the *Masagana 99* area increased dramatically — 28 percent from 1973 to 1974, an additional 1 percent in 1975, and another 10 percent in 1976. In 1974/5, for example, yields averaged 3.3 tons per hectare in the project area and .77 tons in the areas not covered by the project. Predictably, initial production leaps of the magnitude realized in the project area boosted farmers' gross incomes radically. For example, at the end of the program's first year, one study shows, farmers in three participating provinces (in which individual landholdings averaged slightly over two hectares) enjoyed income gains of 118 percent. Since 1976, the total harvested crop has steadily gone up, and in late 1977 the Philippines exported 25,000 metric tons to Malaysia and Vietnam. Total rice exports, including 1977's and 1978's, are expected to total 149,000 metric tons. The repayment problem, which has plagued the program, has grown less severe, but the number of farmers participating has dropped to 249,000, and inflation and cost increases of agricultural inputs have wiped out some of the gains made by the majority of participants.

The impact of the media and messages used in *Masagana 99* has not been evaluated apart from overall impact of the project on production totals and income gains.

OF NOTE:

- The word *masagana* means bountiful harvest and the 99 of the project title refers to the target yield of 99 cavans (1 cavan equalled 44 kilos at the outset of the program but has since been adjusted to equal 50 kilos).
- The basic research related to this project was conducted by the International Rice Research Institute, the University of the Philippines at Los Baños, and the Philippines Bureau of Plant Industry. The pilot phase was implemented by the National Food and Agriculture Council of the Department of Agriculture and Natural Resources, whose efforts were supported by the Bureau of Agricultural Extension, IRRI, BPI, and the U.S. Agency for International Development.
- The Management Information System developed in conjunction with *Masagana 99* was designed to help project managers overcome numerous administrative problems that typically beset agricultural projects: weaknesses in links between information sources and decision-makers, difficulties associated with distinguishing causal factors of production from incidental factors, and problems bearing on the coherence and reliability of information culled from many sources. The MIS adopted includes baseline data, standard indicators on data, "on line" data from the field, regular sample surveys, set procedures for analyzing data, feedback and evaluation, carefully spelled out operating assumptions, and other analytical tools for decision-making.
- The field staff reports to a Provincial Program Officer, who summarizes its comments and relays them first by radio and then by mail to the Management Committee Staff.
- Purchases of consumer goods such as cook stoves, refrigerators, and motorcycles by farm families involved in *Masagana 99* have increased so dramatically in some areas that the new variety of rice is sometimes called *Honda Rice*.

REFERENCES:

"Masagana 99: An Integrated Production Drive in the Philippines," J.D. Drilon, Jr., paper presented at the Seminar on Accelerating Agricultural Development and Rural Prosperity, University of Reading, September 1976.

"An Agricultural Management Information System: Lessons from Masagana 99," Kenneth F. Smith, PASITAM Design Notes, No. 7, May 1976.

"A Communication Behavior Study of Small Rice Farmers: Diffusion and Feedback in the Masagna 99 Rice Production Program in the Philippines," Hernando V. Gonzalez II, unpublished M.A. thesis, University of Hawaii, December 1977.

"Masagana 99: A Renaissance in Agricultural Communication," Vicente C. de Jesus, paper presented to the 3rd Research-Media Workshop of the Philippine Council for Agricultural Research, Davao City, August 1975.

"Masagana 99 Program: Farmers', Technicians', and Credit Agencies' Viewpoints," Eusebio P. Mariano, paper presented to the First Agricultural Policy Conference for Policy and Development Studies, U.P. at Los Baños, April 1975.

Clearinghouse on Development Communication
October 1978

Supported by the U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT • BUREAU FOR SCIENCE AND TECHNOLOGY • OFFICE OF EDUCATION

BASIC VILLAGE EDUCATION
Guatemala

TARGET AUDIENCE:	Indian and Ladino farmers in Guatemala
OBJECTIVE:	To change farming practices and increase production through the effective use of communication
MEDIA:	Interpersonal communication, radio forums, graphic materials
DONORS/SPONSORS:	The Latin American Bureau of the U.S. Agency for International Development, and the Guatemalan Ministries of Education and Agriculture
DURATION:	Implemented in 1973; ongoing
CONTACT:	Prof. Mario R. Dardon, Project Director, Programa de Educación Basica Rural, 2a. Avenida 8 - 53, Zona 1, Guatemala City, Guatemala; Dr Howard Lusk, Chief of Education, Science, and Technology, Latin America Bureau, U.S. AID, Rm. 2245 New State, Washington, D.C. 20523, U.S.A.

DESCRIPTION:

Basic Village Education (BVE) is a five-year experiment aimed at using communications media to acquaint Guatemalan farmers with modern agricultural practices. Its ancillary goal is to increase the effectiveness of extension workers so they can help solve individual and regional farming problems. The plan to test the cost-effectiveness of various mixes of communications media was implemented by the Academy for Educational Development under contract to the Agency for International Development (whose total contribution to the project will cumulatively total at least $1,650,000 by the time the project is completed). The plan originally called for three and, later, for four distinct communications mixes, representing increasing degrees of contact with the rural families "in two vastly different cultural and geographical settings."

In 1973, the project was initiated among the Spanish-speaking Ladinos (Mestizos) in the southeastern part of Guatemala. Roughly 18 months later, the experiment was extended to include the western highlands, where it was directed toward the Quiché-speaking Indian population. In a survey conducted by the BVE staff in 1974, the illiteracy rate was pegged at 64 percent in the Yupiltepeque Valley of southeastern Guatemala and at 66 percent in rural communities near Momostenango in the highlands.

Radio was chosen as the main conduit for imparting new agricultural knowledge and stimulating behavioral change. Two radio stations broadcast eight hours a day, from 5 to 9 a.m. and from 4 to 8 p.m., Monday through Saturday. To attract and maintain a large listening audience, the BVE staff programs about 80 percent of the broadcast time with music, entertainment, and other programs unrelated to agriculture. The remaining hours are devoted to the discussion of farming. The core agricultural program includes a 30-minute "agricultural magazine," radio novels, a question-and-answer interview with an agronomist, and 30 to 40 spots that carry agricultural messages.

The first of the four different communication treatments consists of messages delivered by radio alone. The second adds a village "monitor" — locally selected and trained for about a month — who weekly visits four or five villages that together contain approximately 200 families and who holds late afternoon forums at which recorded radio messages are played on a cassette recorder. The monitor uses flipcharts and posters to spark discussions, gives out take-home sheets, and in some cases, cultivates demonstration plots. A third treatment provides low-level technical assistance from agronomists, each of whom serves roughly 600 families. The BVE field agronomist works with monitors in the villages, conducts plot demonstrations, helps identify local crop-production problems, and advises farmers. He also serves as the monitors' supervisor and trainer and is an important feedback channel from the field. The fourth, added in 1975, employs monitors alone in areas not reached by the radio shows.

RESULTS:

Contrary to expectation, and probably because programming is so carefully tailored to local needs, *radio alone* seems to be having a significant impact on farmers' behavior. This particular experimental design, some say, has created an extended personal communications system rather than a traditional impersonal broadcasting sphere. Also, the monitors and agronomists appear to reinforce the radio messages effectively.

The radio forums tended to attract farmers already disposed to adopting more modern farming practices. But some farmers who did not attend the forums also changed their farming practices. Chief among the changes were the selection of heartier corn seed and the use of fertilizer at flowering and seeding time. Fungicide use also increased among many area farmers, but this change was less marked.

OF NOTE:

- In 1976, the usual effect of low rainfall on crop yields was exacerbated by a drought that occurred in the critical months of July through September.
- The experiment was disrupted by the earthquake in February of 1976. For a month project resources were used almost exclusively in relief activities.
- The introduction of silk-screening in 1976 produced superior graphics, eliminated tedious hand copying, and allowed artists more time to integrate feedback concepts into future illustrative materials.

REFERENCES:

"The Basic Village Education Project: Third Interim Report, Field Operations, June 1975 — 1976," Academy for Educational Development, Washington, D.C., 1976.

"The Basic Village Education Project: Third Interim Report, Evaluation Component, University of Florida, July 1976," Academy for Educational Development, Washington, D.C., 1976.

Clearinghouse on Development Communication
June 1977

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THE LIBERIAN RURAL COMMUNICATIONS NETWORK

AN ACKNOWLEDGEMENT

LRCN would not have been possible without the support of the people of the United States, working through the Agency for International Development. Through USAID's assistance, lowcost and effective communications with rural people are now possible in Liberia for the first time.

Technical assistance has been provided by the Institute for International Research.

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THE LIBERIAN RURAL COMMUNICATIONS NETWORK

The Liberian Rural Communications Network officially began broadcasting in August 1986 in Voinjama, when radio station ELRV started its daily six-hour transmission, followed by ELRZ in Zwedru and ELRG in Gbarnga. At the inaugural ceremonies, large crowds flocked to see inside 'their stations'. Groups of singers performed 'live' for the many small communities listening within the 75 mile primary signal radius but they could also be heard in Monrovia, 150 miles away. Within days, the Voinjama station received requests for messages and music from Mende speakers in neighboring Sierra Leone. Recorded messages of congratulation from stations all over the world were received and broadcast. The first truly local radio network in Africa had not only become a reality, but was being celebrated internationally.

The radio stations broadcast in local languages, three hours in the early morning and three hours in the evening. Small production staffs of six producers get to work at 5.30 in the morning and work until 9.30 at night with a break in the middle of the day. They provide 70% of the programs; the other 30% comes from the Central Production Unit (CPU) in Monrovia. The CPU makes programs with a national perspective, and concentrates on producing material which is more carefully researched and crafted, and that can be repeated in subsequent years. In the first month of operation, the Planned Parenthood Federation has signed a contract for six months; the Expanded Program of Immunization will do a two-month intensive campaign; the Forestry Development Board will broadcast for three months; the Central Agricultural Research Institute has signed a three-month contract; and agencies concerned with oral rehydration therapy also have agreements with LRCN.

Why are these agencies so interested in the radio network? Radio has been organized in Liberia for more than fifteen years. Why did a health specialist say recently: "Now that LRCN is here, everything is different..."?

First, the network reaches rural communities in their own languages. National stations also have broadcasts in the 16 local languages, but primarily broadcast in English. LRCN stations are dedicated to vernacular broadcasts.

Second, the stations are situated in their rural locations, not in Monrovia. They are accessible. People can visit the stations, identify with them, and in a very real sense 'own' them. Illiterate farmers can communicate messages over the radio rather than rely on an intermediary to write a letter. The national stations broadcasting on shortwave barely reach many people, while LRCN stations boom powerful AM signals to their local listeners.

Third, the stations are trying to meet the total information needs of rural people. They are not focussed on a single sector such as agriculture, as is the case in other countries' development radio. LRCN is local development radio, responding to its audience as people, not just as agriculturalists or mothers of sick children.

Finally, the local audience has obligations to its radio station. Listeners must support the station by paying individually small fees for messages. Local development agencies and shopkeepers must contract for programs. With subscription comes commitment.

For all these reasons, LRCN must remain close to its audience. Therein lies its challenge and its main prospect for success.

Wonsuom—A Rural Communication Project in Ghana

by S. T. Kwame Boafo .

The communication infrastructure in most parts of sub-Saharan Africa displays a heavy urban bias in geographical reach, content, orientations, language, and style. Most outstanding and common among the features of the modern communication systems in the region are high concentration and clustering in the cities, inadequacy of information facilities and resources, and limited accessibility to available facilities for people living in the rural areas.

These features serve as a major obstacle to efforts using, on a long-term and sustained basis, communication technologies in the socioeconomic, cultural, and political development in the sub-Saharan African region. The inadequacies in the distribution of communication technologies in the region make it difficult for the bulk of the population who lives in the rural communities to participate effectively in discussing and making decisions on development issues. The gaps and imbalances in communication infrastructure can also create, among people cut off from the mainstream of communication flow, severe disagreement or ignorance of national development goals and strategies. Such conditions can either frustrate or decelerate development efforts. Solutions to this problem which have been proposed and attempted in many regions of the developing world include decentralization and democratization of the communication infrastructure, with the establishment of rural newspapers and local community radio stations as a major focus.

The "*Wonsuom*" rural communication pilot project in Ghana broadly aims at training, research, and experimentation in rural community-based communications, and specifically at providing communication technologies at the grassroots level to enhance the contribution of communication in rural development. "*Wonsuom*" is a Fante expression which literally means "Let's carry it together." It identifies the project and symbolizes the significance of getting the people to participate in development programs in their communities. *Wonsuom* is used both as a call sign for the radio programs and the name of the newspaper. Fante is the main language spoken in the project area. The project, when fully operational, will use a combination of a rural newspaper published in the local Fante language, rural radio broadcasts, radio listening clubs, and slide projectors to carry development-oriented information to the communities in the project area and to mobilize and stimulate the people for development programs.

The *Wonsuom* project is carried out by the School of Journalism and Communication at the University of Ghana with technical and financial assistance from Unesco. The project is based in the Central region of the country, about 80 kilometers west of Accra, the national capital, and covers 22 rural communities with a total population of about 150,000. The adult population in the communities is mainly occupied in farming and fishing.

Programs from Local Communities

The radio component of the project was formally launched in March 1983, after an extensive 14-month preparation and planning period. Programs are produced and transmitted on the local relay station of the national broadcasting corporation on a daily basis. Most of the programs are generated from the local communities and address issues of interest and relevance to the local people. The radio broadcasts deal principally with: a) news and information on local events and significant national events; b) discussion programs involving local community leaders, farmers, fishermen, and extension agents on problems facing the communities and on such development areas as primary health care, agriculture, community development, home management, family planning, and small-scale industries; c) features on the achievements of farmers, fishermen, and other individuals and on development activities in the local communities and elsewhere.

> *"Listening clubs organize performances and competitions among local brass band, singing, story-telling, and wise-saying groups . . ."*

Only the radio and listening clubs components of the project are in the implementation stage because of a number of constraining problems. The problems, which stem from Ghana's deepening socioeconomic crisis, include fuel shortages, electricity rationing, and a general scarcity of goods and services. These factors have created some discontinuities in the implementation of the project and delayed both the publication of the rural newspaper and an evaluative study of the project's reach, penetration, and effects on the local communities. But there are some indicators of the impact.

Feedback and Outreach

Wonsuom radio listening clubs have been formed in the communities by the local residents. Members of the clubs meet on a regular basis to listen to the radio broadcasts, discuss issues highlighted in the broadcasts, and then deliberate on ways of generating development projects in their communities. The discussions and deliberations are recorded for subsequent broadcast on the radio. This helps to carry the views and opinions of the communities on issues of concern to them and create a two-way communication process in the villages.

The listening clubs also serve as the focus of social and cultural life in the communities. The clubs organize performances and competition among local brass band, singing, story-telling and wise-saying groups, and concert parties. These performances are recorded for broadcast which gives access to the radio and recognition to talented local artists. Besides, the listening clubs have helped to unearth from the communities a number of young and middle-aged people who possess leadership qualities, initiative, and dynamism in community development. Such individuals have organized members of the listening clubs to undertake self-help development projects such as farming, pit-latrine construction, clean-up campaigns, and adult literacy classes in the local languages.

An evaluation has been scheduled to gather more empirical data on the impact of the project. It is anticipated that newspaper reading clubs will be organized when the newspaper component of the project is implemented to complement the radio listening clubs. Slides have also been planned on development issues for showing by development agents at the meetings of the clubs and other organized social groups in the communities. In these ways, the *Wonsuom* rural communication project reinforces development messages through radio transmission, through the newspaper, through slides, and through interpersonal communication. ■

S. T. Kwame Boafo, Ph.D., is a Lecturer in the School of Journalism and Communication, the University of Ghana, in Legon, Ghana.

Development Communication Report

Clearinghouse on Development Communication

Autumn 1984
No. 47

AED

ACADEMY FOR EDUCATIONAL DEVELOPMENT

PROJECT SUMMARY

COMMUNICATION FOR TECHNOLOGY TRANSFE IN AGRICULTURE

OBJECTIVE: To develop and demonstrate a system and methodology for using multi-media communication support that integrates mass media (principally radio and graphic/print media) and interpersonal contacts to help attain widespread beneficial adoption by farmers of appropriate new and/or underutilized technologies.

DURATION: 1985 - 1989

SPONSOR: The Offices of Education, Rural Development and Agriculture of the Bureau for Science and Technology of the United States Agency for International Development

The Academy for Educational Development is administering a five-year project to develop and demonstrate a system and methodology for using multi-media communication to accelerate widespread beneficial adoption by farmers of appropriate high and low input technologies. The Project integrates mass media (principally radio and graphic/print media) with interpersonal contacts, which characterize conventional extension in the developing world. The Communication for Technology Transfer in Agriculture (CTTA) Project works with existing institutions in the public and private sectors to develop effective communication networks, with particular emphasis on strengthening linkages among extension, research, the agrosupport sector and farmers.

CTTA incorporates the experience of other development communication projects in agriculture and other sectors such as health and education, and that of agricultural extension. The strategies to be developed will integrate approaches and knowledge from agricultural communication, extension and research; behavioral analysis; social marketing; instructional design; and development communications. The methodology and delivery systems will seek to increase the impact of technology transfer programs at costs affordable for sustained adoption by developing nations.

One primary and eight collaborating pilot sites will be selected in nine countries in Africa, Latin America and Asia. Communication interventions in each will be based on selected farming practices and technologies, behavioral analyses, pretested messages and materials, trial product testing, and continuous formative evaluation. Summative evaluation will occur concurrently with implementation.

Special effort will be made to identify new and/or underutilized appropriate, adapted technology for the interventions at each pilot site and to include private as well as public sector organizations in project implementation.

A systematic communication strategy based on careful technology identification, developmental investigation and continuous monitoring through formative evaluation and feedback mechanisms will guide the CTTA multi-media program. Communication interventions will integrate mutually reinforcing multiple channels such as radio, graphic and printed materials; conventional extension-type interventions (interpersonal contact, group meetings, demonstrations); and newly created devices and materials. This systematic approach will inform, instruct and reinforce adoption of improved agricultural practices.

Documentation will include field notes, reports, a videotape series, and an instructional handbook. Conferences, seminars, workshops, magazine and journal articles, newsletters, and extensive interinstitutional and interprofessional contacts will be used for worldwide diffusion of project experience and results.

The project team has strong technical capability and experience from similar multidisciplinary and multisite projects. Field directors have demonstrated expertise and experience in conducting agricultural and/or communication programs in developing countries, and a cadre of talented specialists in agricultural technology, communication, social marketing, behavioral analysis, agricultural economics, and evaluation has been identified to provide on-site advisory and consulting services throughout the project.

The College of Agriculture and Life Sciences of Cornell University and Applied Communication Technology, Inc., are subcontractors for the CTTA Project. Collaborating institutions include the University of Wisconsin, Iowa State University, Virginia State University, and Needham Porter Novelli. Consultants will be drawn from these institutions and from around the world.

Academy for
Educational
Development

AED
International Division

SWAZILAND
DEVELOPMENT
COMMUNICATIONS

SWAZILAND DEVELOPMENT COMMUNICATIONS

Currently in Swaziland, there are a variety of ministries, agencies, and local institutions, including non-governmental organizations, which conduct extension efforts. Still, there remains a great potential in Swaziland for strengthening the access to, and delivery of, practical development information. If useful information could be made to flow to and among the people more rapidly, effectively and systematically, it might be put to use in vital areas such as safeguarding health, optimizing the use of agricultural inputs and helping local groups to organize and carry out development efforts.

Radio is at present the most pervasive rural communications medium. Although one siSwati-language newspaper is already published and another was scheduled to begin publication in late 1984, rural distribution of those publications is poor, and functional illiteracy of the rural population is relatively high. By establishing a development communications planning and training facility, radio, print, and other media will be linked for more cohesive extension efforts. Media messages will be integrated with other development information provided through extension agents and rural training programs.

The Swaziland Development Communications Project will provide assistance to: (a) train Swazi communicators in the skills required to use mass communications to promote development more effectively; (b) reduce constraints on available capacity for disseminating development information by providing modest amounts of equipment and commodities; (c) encourage Swazis to set development priorities and to plan and organize activities in support of such priorities; and (d) create an institutional base for development communications in Swaziland. The institutional base will be a new Center for Development Communications at the Swaziland Broadcasting Service (SBS).

The project will focus on in-country training of communicators of all development ministries, staff members of SBS and community leaders; a limited number of long-term training opportunities in the United States; and the design and implementation of communications support for specific development projects.

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Swaziland

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Telephone: 42761

DEVELOPING COUNTRIES FARM RADIO NETWORK
Canada

TARGET AUDIENCE: Small-scale farmers of developing countries

OBJECTIVE: To increase food supplies and improve the health/nutrition of subsistence farmers and their families

MEDIA: Radio scripts, cassette tapes, print

DURATION: 1979; ongoing

DONORS/SPONSORS: Canadian International Development Agency, Massey-Ferguson Ltd., University of Guelph (Canada)

CONTACT: George Atkins, Director, Developing Countries Farm Radio Network, English Language Division, c/o Massey-Ferguson Ltd., 595 Bay St., Toronto, Ontario, Canada M5G 2C3; Developing Countries Farm Radio Network, French & Spanish Language Division, c/o University of Guelph, Guelph, Ontario, Canada N1G 2W1

DESCRIPTION:

As the populations of developing countries continue to grow, land formerly used for cultivating small-scale, domestic consumption crops is increasingly appropriated for larger-scale, export crops. This process puts pressure on the subsistence-level farmer to grow more crops on less land. When the Developing Countries Farm Radio Network (DCFRN) was established in 1979 the vast majority of small-scale farmers had been largely by-passed by most development programs aimed at increasing food supplies in the Third World. To help solve this predicament, DCFRN provides information on simple , practical farming methods in order to improve national agricultural self-reliance, nutrition, and the welfare of small producers.

DCFRN is committed to assisting small farmers increase their food supplies by providing established radio stations and other local channels of communication with packages of practical agricultural information. Information is assembled on appropriate, simple, transferable technologies used by grass roots-level farmers in the developing world to increase food production, decrease post-harvest losses, and to make more efficient use of food. Only practices that have been developed, tested, and proven in the developing world, and are adaptable in other developing countries are included in DCFRN's information packages. There should be no or very low implementation costs, by relying only on local resources, and requiring neither chemicals nor unfamiliar types of plants or breeds of animals. Also, the advocated methods need to be straightforward enough to communicate effectively by radio.

Information packages consist of up to 17 radio scripts, an optional cassette on which all scripts in the package are recorded, and The Blue Sheet, the Network's newsletter. Packages are available in English, French, and Spanish. The simple scripts are written so that local broadcasters and other agricultural communicators — the links between DCFRN and farmers — can readily interpret the materials linguistically and culturally for the farmers they serve. They include illustrations to help communicators understand what they are conveying. Scripts cover a wide variety of agricultural or health and nutrition issues, all within a development context. Agricultural topics have ranged from improving manure to getting more milk from dairy cows. Each package also contains at least one script on rural health problems.

The Blue Sheet, in addition to providing up-to-date information about the Network, also covers other development issues not found in the radio scripts. "The Professional Improvement Corner," a regular column, gives broadcasters pointers on how to make their broadcasts more captivating for listeners, and many such recommendations come from Network participants.

Feedback from the Network's participants is crucial in compiling subsequent material for distribution. The only requirement for receiving the free scripts and cassettes is that an enclosed information poll be filled out and returned to DCFRN headquarters. Participants are asked which segments were found to be most useful, as well as questions whose answers determine the content of future packets. There is also room for comments and suggestions. This data is then collected, analyzed, and integrated into later packages.

RESULTS:

Overall, DCFRN has proven itself as an educational tool. Its success is perhaps best evidenced by the fact that over 600 rural communicators in more than 100 countries regularly disseminate DCFRN information in more than 100 languages. Through radio alone the information is estimated to reach over 100 million listeners. Feedback from participants shows that farmers receive and use information that is appropriate to their particular needs.

OF NOTE:

- In addition to radio broadcasts, DCFRN information has been used in farm and health extension work, newsletter and newspaper articles, government pamphlets, posters, classroom teaching, video tapes, filmstrips, loudspeaker broadcasts, puppet shows, and in other ways.
- Information communicated is totally non-political and the scripts are prepared in a culturally and religiously neutral style in order to appeal to as many listeners as possible. A personable, informal style is followed, as if one farmer were advising another.

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Clearinghouse on Developemnt Communication
March 1986

TÉLÉ-NIGER
Niger

TARGET AUDIENCE:	Nigerien children between the ages of about seven and twelve (approximately 700 children in the pilot phase and 9,000 children in 1975)
OBJECTIVE:	To provide rural children with an education that will equip them for rural life and that will in general foster rural development and not urban migration
MEDIA:	Television, printed materials, and interpersonal communication
DONORS/SPONSORS:	The French Government (through 1971) and the Nigerien Government
DURATION:	Conceived in 1963; implemented in 1964; ongoing
CONTACTS:	L. Theresa Silverman, Brookdale International Institute, P.O. Box 801, Stony Brook, NY 11790 U.S.A.; Max Egly, L'Agence de Coopération Culturelle et Technique, 19 Avenue de Messine, 75008 Paris, France

DESCRIPTION:

With the education mandate of the 1961 UNESCO meeting of African ministers still fresh in its policy-makers' minds and with only 5 percent of its school-aged children enrolled in classes in that year, Niger began an assessment of its educational sector that prompted it to ask France for help in reforming and expanding existing educational services. Talks between representatives of the two nations got underway in 1963, and by 1966 Télé-Niger was a reality to the 22 monitors and the roughly seven hundred children involved in the pilot phase. Designed to test the effectiveness of "active education" in a setting typified by shortages of money, technical skills, hardware, and trained teachers, the project reflects Niger's commitment to meeting the educational needs of rural folk without turning schooling into either a passport to overcrowded cities or into a mold for an agricultural stereotype. In the shorthand of pedagogues, the project's goals are ruralization, integration, and dynamism.

Television was selected as the primary educational medium for several reasons. It obviates the need for highly skilled teachers. It is capable of reaching remote areas on a regular basis. It is democratic, insofar as all the children in the original classrooms receive teaching of the same quality and insofar as "television teachers" cannot very well play favorites. Moreover, the French were willing and able to provide the technical assistance that a television operation would require. Another factor related to the use of television, the utter novelty of TV in Niger, was exploited creatively and to advantage but was apparently not decisive at the planning stages of the project.

A key feature of Télé-Niger is the presence in every classroom of a monitor. Subjected to ten weeks of in-service training, semi-annual refresher courses of from seven to ten days each, regular meetings with counselors, and brief TV broadcasts designed to clarify lessons and duties, the monitor is equipped to handle the children's questions and typical classroom crises. Yet, it is axiomatic that the monitor not be a highly educated professional: using skilled labor where semi-skilled labor is more than adequate would defeat part of the purpose of the project. More important, the monitors as a group have greatly surpassed the expectations of those who designed the project and hired them, perhaps because the monitors' lack of preconceptions allowed them to be quite open-minded and empirical in their supporting roles in the classroom.

The production of the television programs, originally but no longer in the hands of French experts, takes place at studios in Niamey. Production equipment is fairly simple — video tape recorders, cameras, work rooms, storerooms, transmitters and a few other pieces of hardware — but production values have kept curriculum specialists and technicians from falling into ruts. The ingredients of each program (manual activities, games, skits, written exercises, etc.) vary from day to day, and the effort required to keep the math teacher apprised of what the French teacher or geography teacher is up to can be exhausting. This effort bears fruit, however, and some production features have survived evolution and perpetual experimentation: the "pedagogical variety show," "diversified repetition," review via concise "commercials" for previously studied concepts, and the treatment of each lesson as both a self-explanatory component and a part of a broader package of programmed instruction have proved their worth and weathered well.

RESULTS:

No rigorous evaluation of all aspects of Télé-Niger has ever been conducted, partly because research was from the beginning accorded less priority than production and partly because no control group was isolated in the early days of the project to use as a basis of comparison. Outside observers have, however, conducted several small-scale studies, and in-house formative research has been conducted routinely since the inception of the project. The key components of this internal research have been anthropological descriptions of local culture by the foreign staff, studies of how Nigerien children relate to the pictoral image, interviews with village children, recorded observations of the dynamics of the classroom, and feedback culled from the written work of the Télé-Niger participants.

What has been established to the satisfaction of the Télé-Niger staff is that the TV classrooms are not besieged by the problems that surrounded the traditional Nigerien classroom: poor attendance, high dropout rates, and a high incidence of grade repetition. The dropout rate among regular primary school students in the 1960s, for example, approached 40 percent while 674 of the original 716 students enrolled in Télé-Niger classes in 1966 finished the four-year cycle in 1970 (a dropout rate of less than 6 percent). Similarly, the children were loathe to skip school: a one-week experiment in which the classes were unmonitored revealed that attendance and attention in the unsupervised classrooms remained high. A later UNESCO study corroborated these findings: its executors found that the content, if not the language, of the broadcasts was truly local, that the programming encouraged openness to experience as well as knowledge acquisition, that the medium of television was exploited positively and creatively, and that the project made good use of semi-skilled people in the classroom. Finally, the project has expanded to include some 9,000 students (some of them urban) and has been taken over completely by Nigeriens.

The problems identified in various studies relate to the use of French in the broadcasts and to the quality of education received by students in the television classroom. In particular, TV students performed less well than students in the traditional classroom in standardized math and grammar tests. To help assuage this problem, a fifth year was added to the televised curriculum in 1970.

OF NOTE:

- All but the simplest camera shots were avoided until the children became accustomed to the medium of television. Close-ups, angle shots, cutaways, and other sophisticated techniques were introduced only gradually, so that the students were not forced to come to grips all at once with an alien visual language.
- The appeal of television's "concrete" message has proved strong in Niger, where "truth" is defined as knowledge based upon what can be seen and where the language of instruction (French) is not the language spoken in the students' immediate environment.
- The commitment of the television teachers to the new methods was shaky in the early years of Télé-Niger both because they were ill-served by their training in established teaching techniques and because they tended to feel that they would eventually return to the conventional classroom.
- The minimum age of admission to the Télé-Niger program was established on the basis of a traditional Nigerien concept of maturation, *Lakkal* — a combination of intelligence, savoir-faire, acceptable social behavior, power of memory, and the ability to adapt.
- The chief difference between the Télé-Niger approach to education and the conventional Nigerien approach relates to the child's verbal expressiveness. Traditionally, a Nigerien child is expected to be silent in the presence of adults, whereas the Télé-Niger approach emphasizes a child's right to question and respond vocally to his environment and to adult company.
- The Télé-Niger approach has been schematized as a "double funnel": children are encouraged to gather raw materials and data from real life, to analyze and order that knowledge and those materials in the classroom, and to reintegrate what has been learned into quotidian life.

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VIDEO-BASED TRAINING FOR RURAL DEVELOPMENT

Peru

TARGET AUDIENCE: Peruvian farmers in the coastal plains, Andean highlands, and tropical forests

OBJECTIVE: To develop and apply on a large scale, audiovisual methodology to train farmers in appropriate farming techniques

DONORS/SPONSORS: Government of Peru; United Nations Development Programme (UNDP); Food and Agriculture Organization (FAO); Technical Cooperative Program; Dutch bilateral assistance; Friedrich-Ebert Foundation

MEDIA: Interpersonal communication, videotape, print

DURATION: 1974 - ongoing

CONTACTS: Manuel Calvelo Rios, FAO-CESPAC, Per 76/003 Aptdo. 4480, Osa Mayor No. 118-Monterrico, Lima, Peru; Colin Fraser, Development Support Communication Branch Chief, FAO-UNDP, Via delle Terme di Caracalla, 00100 Rome, Italy

DESCRIPTION:

When, in 1969, the government of Peru began a nationwide program of agrarian reform, a massive supporting education effort was needed to help campesinos (rural farmers) to quickly acquire basic farm management skills and modern agricultural techniques they would need as new landholders. To run this massive education program, the government of Peru in 1970 set up the Centro Nacional de Capacitación y Investigación para la Reforma Agraria (CENCIRA)—the National Agrarian Reform Training and Research Center—within the Ministry of Agriculture. Financial assistance for this effort was provided by UNDP, while technical assistance came from the FAO. In February 1974, CENCIRA enlisted the expertise of Manuel Calvelo Rios, an early pioneer in Chile in video-based training. A video production center, CESPAC (the Centro de Servicios de Pedagogía Audiovisual para la Capacitación), was established by CENCIRA in Lima. To meet specific needs of the varying geographic areas—coastal plain, highlands, and tropical forest—five regional production centers were also set up under CESPAC.

The first step was to develop a rigorous 90-day program to train audiovisual teachers as video producers. Training covered all parts of the video-based training process including research, script-writing, field recording, editing, testing of curriculum with campesinos, etc. Such broad-based training made the teams' members interchangeable. Immediately following the 90-day training period, pairs of trainees would form a production unit and begin producing courses. The number of lessons per course offered ranges from four to thirty. Each lesson tape is approximately 18 minutes long and is generally accompanied by simple print materials to be handed out to campesinos. Agricultural cooperative farmer members decide which course they want and CESPAC then sends playback equipment to the local extension unit. One lesson per day is presented, either in the morning before the campesinos go to the field or in the afternoon when they return. In addition to the 18-minute video presentation, there is discussion and review of the print material, making the total length of each lesson approximately two hours.

Production equipment falls into four categories: that which is used in the filming unit, the playback unit, the recording unit, and the editing unit. Broadcast over an educational TV circuit, course material (much of which is taped in the field) is edited in the microstudio where supplementary material is added. Programs taped in the field are carried back to the campesinos via the playback unit. In all phases of planning and production, feedback from the target audience plays an important role.

RESULTS:

An evaluation made in January-February 1980 showed that 80 percent of the *campesinos* liked the video-based training. There was, however, some criticism that cooperative managers selected the courses without prior consultation with the *campesinos* and then made attendance compulsory, and that *campesinos* were ignored by CESPAC in the planning and production of video courses. By November 1981, the Peruvian project had made more than 600 18-minute video lessons, trained over 140 video producers, and reached some 102,000 *campesinos* with video-based training.

The latest available cost figures show that for every 1,000 *campesinos* taught by the courses, production costs are approximately $12.00 per *campesino*. This amount includes the depreciation of equipment, cost of consultant expertise, etc. The video equipment portion of the total cost is only 10 percent of the program, which contradicts the widely held belief that the costs of this type of instruction are high due to equipment costs.

Video has proved to be an invaluable tool for grass-roots-level training. The audiovisual nature of video overcomes the problem of high illiteracy in rural areas at one stroke. Another problem is that extensionists and trainers themselves lack training and knowledge. Training programs on video, produced in conjunction with good subject matter specialists, will upgrade and standardize the quality of information being transmitted to farmers. Yet another problem is the shortage of extension and training staff in rural areas. Use of video can help maximize the effectiveness of their training activities with farmers and enable them to present, in one audiovisual course, a complete agricultural operation or crop-growing cycle.

Following the purchase of new equipment (made possible by a $500,000 budget from the Peruvian government), CESPAC decided to make VTR training methodology available to regional and local development projects in Peru. An intensive training course for VTR trainees was set up which enables them to apply CESPAC's courses to their own activities, using CESPAC's equipment and course materials.

The Peruvian project has spun off similar, although smaller, projects in Mexico, Honduras, Paraguay, and Brazil, and has also provided consultant advice in Argentina, Ecuador, the Dominican Republic, and Bolivia. At a meeting of extension directors from all over Latin America and the Caribbean held in Santo Domingo in April 1981, a Peruvian video presentation and discussion resulted in a resolution that the FAO be called on to promote video-based farmer training methodology throughout the region.

OF NOTE:

- Logistical problems of maintaining the regional production units led to the decision to close the regional centers. As an alternative, CESPAC sends out teams of audiovisual teachers to produce courses in the different ecological zones to meet peoples' specific geographic and environmental needs.

- Although purchased more than six years ago, all of the equipment (3/4" color Umatic cassette for program production and 1/2" Betamax cassette for playback with two audiotracks for two languages—Spanish and/or Quechua and Aymara) is still working.

- The Peruvian government was so pleased with the success of the program that the original 34 extension units equipped with video playback units were increased to 150.

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The Training and Demonstration System of Agricultural Extension: A Nigerian Experience

by Richard China and Peter Langmead

Bauchi State Agricultural Development Program (BSADP) was established in 1981 by the Nigerian Federal and Bauchi State Governments with the assistance of the World Bank. The objective of BSADP is to increase state agricultural production by three to five percent a year over a five-year term. This is being achieved by the development of an effective extension service and by providing easy access to agricultural inputs and markets through construction of village sales points and feeder roads. The program covers 66,000 square kilometers of semi-arid savannah and serves 455,000 farm families with an average farm size of three hectares. The principle crops are millet, sorghum, maize, rice, groundnut, cowpea, cotton, and vegetables. Most farmers cultivate by hand but the use of draft oxen is increasing. All farmers keep small numbers of livestock.

In 1982 BSADP took over the State Ministry extension service with a village extension agent to farm family (VEA : FF) ratio of 1 : 1659. Prior to BSADP, the extension service had pushed sole crop packages, ignoring evidence that farmers' mixed cropping systems were more efficient in their use of labor, water, light, and nutrients. Moreover, VEAs with their negative attitudes to traditional farming and inadequate technical background, were expected to convince farmers to adopt these sole crop packages by theoretical instruction only. As a result, VEAs commanded little respect among farmers and made little impact. Thus the main challenge for BSADP has been to devise recommendations which fit into traditional cropping systems; to ensure effective communication; and to change staff attitudes.

Implementation of T & D

In early 1982, BSADP recruited two consultants in Extension and Media to reorganize the extension service. These were Richard China (Extension Specialist) and Peter Langmead (Media Specialist). A modified T&V system called Training and Demonstration (T&D) was devised, and media facilities were developed. All extension staff underwent re-orientation courses to introduce T&D and increase their appreciation of traditional cropping systems.

VEAs were assigned to 232 village sales points. As in T&V, small groups of VEAs receive topical training one day every fortnight from trainers at 70 selected sales points (SPs); however, in T&D, training concentrates on the practical skills of how to demonstrate new methods on farms, and each trainer is equipped with a Mobile Video Unit (MVU).

Every fortnight the 'MVU Trainers' are briefed by the Extension Specialist on the current package. These packages contain simple illustrated notes for VEAs; video dramas, which communicate not only the T&D message but also illustrate the approach that VEAs should adopt in their dealings with farmers; audiocassettes for VEAs to play to farmer groups; demonstration samples such as new seed varieties in labelled specimen bottles and various chemicals; pesticide sprayers and the other inputs necessary to establish demonstration plots. To boost staff morale and credibility with farmers, extension and training staff are provided with colorful BSADP caps and badges.

To provide more background knowledge to T&D messages and improve training skills, trainers and supervisory staff frequently attend short courses conducted by the Training Department.

Demonstrations

Before the planting rains, VEAs demonstrate seed dressing and how to use fertilizer and pesticides in mixed crops. During the rainy season each VEA establishes his own plot, to further practice skills learned in training, and assists up to eight farmers in different hamlets to establish 0.2ha mixed crop demonstration plots with improved seed, fertilizer, herbicides, and insecticides. To distinguish plots from surrounding crops, and to attract other farmers attention, each plot is marked with a large BSADP flag. After harvest VEAs demonstrate crop storage chemicals, conservation of crop residues, and how to mix concentrates for livestock feeding. During the dry season, to reduce disease buildup and market saturation from continuous cropping of traditional vegetables, farmers in the flood plains are given samples of exotic vegetable seeds. Home economics agents demonstrate to farmers' families preparation of these new vegetables. Small irrigation pumps and improved vegetable production techniques are also demonstrated.

Demonstrations are conducted in groups, and mini-field days organized on successful plots so that other farmers can see the results of using new methods. The aim of the plots is not to show farmers how to farm but to give farmers an opportunity to observe how a wide range of improved technology can be incorporated into crop mixtures and how these methods perform under their own conditions. Not everything included in the plots is absolutely right for all farmers and not all demonstrations work out as intended. Farmers are encouraged to discuss what they like, what they do not like, and the reasons why. Feedback from these discussions helps to determine the next year's extension plan, and which seed varieties and chemicals should be made available in greater quantities.

Supervisors, as well as ensuring that VEAs maintain standards, conduct on-farm adaptive research trials. The function of these trials is to see how new ideas gleaned from research institutes work in the field. Successful practices which gain farmer approval may then be included in VEAs' demonstration farmer plots the following season.

(continued)

Media Center for the Bauchi State Agricultural Development Program in Nigeria. Extension agents learn to produce audio and videotapes which are shown to farmers in the field.

Mass Communications

To communicate with larger numbers of farmers, the MVUs show the T&D video dramas in villages, and in the near future fixed video units will be installed at the largest sales points. In addition, a twice-weekly radio forum complements the current T&D message.

Training of Media Staff

The equipment which is used to make the video dramas was installed and initially operated by the media specialist; however instruction was given in camerawork, simple insert and assembly editing techniques, and sound recording, so that the dramas are now produced by local staff.

Use of Media

The fortnightly T&D video package cycle is very short when one considers the high media input. In Nigeria a large proportion of media produced by outside agencies tended to be inflexible, costly, and quickly out of date. For example, a film can take over four months to produce, and can only be put to use the following season. Film serves a purpose, but it is not the purpose of T&D. The only media which are efficient, cost effective, and can sustain a rate of output suited to a two-week deadline are those which are produced electronically—video and audio.

Video can emulate nearly every other form of media: slidetapes, films, flipcharts, puppet shows, etc. Moreover, video can be produced so rapidly it can be used to direct extension staff and communicate with farmers without message dilution, and can be automated to simplify operation.

Contrary to public belief, electronic equipment survives very well in adverse conditions. The MVUs are designed to withstand shocks and, whether installed in four wheel drive vehicles or Peugeot 404 vans, cause few problems. Similarly, high dust, temperature, and humidity levels have not seriously impaired operation.

Evaluation

VEAs are tested fortnightly on their T&D comprehension and results computerized so that performance can be continuously monitored. Similarly, demonstration plots are systematically scored. The best VEAs receive prizes and are considered for promotion and further training. This combination of theory tests and plot scoring has generated healthy competition and ensures most VEAs pay attention to training. Inevitably some VEAs are lazy, uninterested, or incompetent and appropriate action is taken against those who fail to maintain satisfactory standards.

Feedback on T&D response occurs at the fortnightly trainers' briefings. Specialist staff evaluate demonstration farmers' response. Recent surveys indicate 95 percent of demonstration farmers wish to use improved short season sorghum and 76 percent want to use herbicides next season.

Performance

The VEA : FF ratio has increased to 1 : 1153 and by 1988 will reach 1 : 1000. Further expansion is limited by financial constraints and the desire to improve quality rather than number of contacts. There is now one demonstration plot per hundred farming families. Surveys indicate 65 percent of farmers listen to the T&D radio forum, and MVUs give up to three video shows a day to groups of 40 farmers or more. As a result, sales of fertilizer, seed, and chemicals have risen sharply.

> *"The success of the T&D system with its media support is attracting considerable interest . . ."*

At this stage it is difficult to assess the long-term impact of extension on agricultural production when annual yields vary by 50 percent or more due to fluctuations in rainfall. However, there is no doubt that the discipline of the fortnightly cycle with emphasis on practical demonstrations supported by in-house media production has rejuvenated the local extension service. Farmer confidence in VEAs has increased and extension is making an impact on farmers vis-a-vis the adoption of new farming methods. The success of the T&D system with its media support is attracting considerable interest within Nigeria and from the West Africa Projects department of the World Bank. ■

An Agricultural Extension Specialist, Richard Chinn has worked in Smallholder Development Projects in the South Pacific, Liberia, and Nigeria.

Peter Langmead, a Media Specialist, has been engaged with incorporating media techniques in Agricultural Extension Systems, mostly in Nigeria.

TELEMEDICINE IN ALASKA
U.S.A.

OBJECTIVES:	To improve access to and the quality of health care in rural Alaska
TARGET AUDIENCE:	Eskimo, Indian and Aleut villagers
MEDIA:	ATS-1 — two-way satellite radio; ATS-6 — satellite-TV, videotape, computerized health records
DONORS/SPONSORS:	U.S. Department of Health, Education, and Welfare (the Indian Health Service, the Lister Hill National Center for Biomedical Communication); U.S. National Aeronautics and Space Administration
DURATION:	ATS-1 began in 1971 and will continue until replaced by another system (tentatively, in late 1977); ATS-6 began in 1974 and ended one year later
CONTACTS:	Dr. Edwin B. Parker, Institute for Communication Research, Stanford University, Stanford, CA 94305, USA; Dr. Heather Hudson, Academy for Educational Development, Inc., 1414 Twenty-Second Street, N.W., Washington, D.C. 20037, U.S.A.; Dr. Dennis Foote, Academy for Educational Development

DESCRIPTION:

Experiments in the use of telemedicine in Alaska began under the auspices of the Indian Health Service (the arm of the U.S. Public Health Service responsible for providing health care to native Alaskans). Faced with the problem of servicing scattered small villages in remote regions and thwarted by the lack of reliable communication channels in the bush, the agency turned to telemedicine in the hope that consultation on a regular basis would improve village health services.

Telemedicine became a part of daily life for 17 villages in the Tanana region when the National Aeronautics and Space Administration, IHS's partner in the telemedicine experiments, made the Applications Technology Satellite-1 (ATS-1) available in 1971. The ATS-1, still operating as of 1977, is a voice-only communication medium supported by simple and inexpensive ground equipment: modified taxicab radios and ten-foot diameter antennas of metal mesh. By providing reliable communication channels between villages and the district hospital, the ATS-1 functions as a medical support system; it enables village health aides to provide health-care services under a doctor's supervision and helps evacuation planes to reach patients in critical condition swiftly.

The village health aides trained as part of the telemedicine experiments are nominated by their communities and receive up to 16 weeks of training conducted by the Public Health Service both in the field hospital and on the job. Each aide leaves the intensive course equipped with a drug kit, a diagnostic reference manual, instruments, and new knowledge. In the village, the aide turns on the radio at a scheduled time each day to receive a "doctor call" from the regional hospital. During the radio consultation, the aide reports symptoms, answers the doctor's request for more information, receives professional advice, and helps the consulting doctor determine whether the patients in question need to be evacuated.

While the health aides remain the mainstay of telemedicine in Alaska, they played only a minor part in a one-year experiment carried out in 1974-75. The ATS-6 experiment, which relied upon the use of a much more sophisticated and powerful satellite than the ATS-1, added a video component to telemedicine that enabled doctors to diagnose difficult cases by using TV. The experiment, in which two well-equipped clinics in fairly large villages were linked to a field hospital and a referral hospital — was run while a problem-oriented computerized medical record system (Health Information System) was being established in Alaska. Up-to-date records of patients were collected at a central point, put into the computer, and made available at all sites; the computer also enabled itinerant nurses to identify villagers who needed PAP smears, inoculations, eye and ear examinations, etc.

RESULTS:

Since the introduction of the ATS-1, the capacity of existing health facilities to handle emergency cases, solve administrative problems, and answer requests has increased, and service has improved. In addition, villagers demonstrate an increased willingness both to seek medical advice and to follow prescribed treatments. More patients now receive the benefit of a doctor's advice and more are treated for diagnosed ailments than ever before. Moreover, the number of contacts between doctors and health aides increased by 400 percent during the first year of the experiment.

In general, it has been difficult to show a connection between changes in aggregate morbidity, mortality, and hospitalization statistics on the one hand and the improvements in communication on the other. However, most evaluations of the ATS-1 experiments have been positive; and partly as a result of these evaluations, the State of Alaska and the Public Health Service are now implementing a satellite system through a commercial long distance telephone carrier.

The ATS-6 experiment was also deemed worthwhile by the health-care providers who took part in it. But while participants claim that the video component of telemedicine enabled them to expand and improve health service somewhat, many doubted that the improvements made possible by the video link were worth the expense and the inconvenience. In contrast, these same people approved unanimously of the problem-oriented computerized system of record-keeping that was developed in conjunction with the experiment, and the IHS plans to introduce the system statewide.

OF NOTE:

- Some aides invite their patients to listen to the long-distance consultations.
- Doctors in remote locations were offered the chance to participate in a series of round-table discussions via satellite, but the program fizzled because IHS doctors in Alaska have such demanding caseloads that they couldn't follow a rigid time schedule. However, a course on cardiac care was offered to nurses at regional hospitals via the satellite and was well-received.
- Most health aides are village women with at least a fair command of English.
- Since the community recruits its own health aide, acceptance of the program tends to be high, and staff turnover is kept at a minimum.
- Besides appreciating its medical function, villagers value the radio system as a means of keeping in touch with other villages, particularly with friends and relatives who are hospitalized.
- When asked if they had learned anything in particular from listening in on consultations, six of the nine health aides in villages with satellite link-ups mentioned specific health facts. None of their counterparts in the control villages could recall specific information related to cases.

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Clearinghouse on Development Communication
October 1977

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UNIVERSITY OF WESTERN ONTARIO TELEMEDICINE
(MOOSE FACTORY EXPERIMENT)

Canada

TARGET AUDIENCE:	Personnel of Moose Factory Hospital, a northern nursing station, and the University of Western Ontario Hospital
OBJECTIVE:	To provide improved medical access for residents of northern Canada by linking medical facilities there with the university hospital
MEDIA:	Satellite, television, one-way video, two-way audio
DONORS/SPONSORS:	Federal Departments of Communications and of Health and Welfare (Canada); Department of Diagnostic Radiology and Nuclear Medicine at the University of Western Ontario, London, Ontario
DURATION:	October 1976 to February 1977
CONTACT:	Dr. Lewis S. Carey, Department of Diagnostic Radiology and Nuclear Medicine, University of Western Ontario, London, Ontario, Canada

DESCRIPTION:

The Moose Factory Telemedicine Experiment (U-6) used the communications facilities of the Hermes experimental satellite to link a small hospital and a nursing station in northern Canada with the University of Western Ontario Hospital in London, Ontario. Because of the severe climate and the transportation and communication constraints imposed by distance and ionospheric conditions, the approximately 10,000 Cree Indians and Inuit residents of 19 villages of northern Ontario and northern Quebec had only limited access to medical services, depending almost entirely on the facilities of local nursing stations and one regional hospital. The U-6 experiment, begun in 1976 and operated from 8 A.M. to 12 noon every second day until February 1977, tested the Hermes spacecraft's ability to improve the Canadian situation by extending university-based medical services to the north. By providing communication between the isolated northern nursing station, the base hospital (Moose Factory), and the university hospital, the satellite facilitated discussions of diagnoses and patient management among the various levels of the health-care system. Reliable audio links between the nursing station and the base hospital allowed for the transmission of electrocardiograms (EKGs) and patient documents and the handling of administrative matters, and made it easier to obtain second opinions and make decisions about patient transfers. It also enabled families to keep in touch with hospitalized relatives.

The base hospital was equipped for one-way video transmission to the university hospital, as well as for voice, facsimile, electronic stethoscope, and EKG transmission. Cameras at the base hospital were remote-controlled from the university hospital.

RESULTS:

The experiment indicated that a telemedicine system can usefully support medical services and should complement, not replace, a program of visiting specialists. It also revealed the need for increased awareness of diseases and conditions of the north; for encouraging medical students to practice there; for upgrading skills--particularly technological--of northern nurses; and for exploring further the requirements for high quality image transmission.

On the whole, the response to transactions was positive, particularly to those involving diagnosis and patient management. Of the 211 transactions recorded in the nursing station-base hospital program, nurses rated 87.6 percent as good to excellent. Visual access provided by satellite transmission was particularly important in psychiatric transactions; in many cases, a patient's mannerisms played an integral part in the medical assessment.

The experiment paved the way for encouraging accreditation of remote health-care sites, for on-the-job continuing education, and for the training of native medical students in the north. The difficulties of travel and transportation in the north seriously affect the provision of medical care. The experiment showed that reliable communications can make a significant contribution to improving health-care delivery, effectiveness, and efficiency.

OF NOTE:

- The physician-population ratio in the north is 1:1490, compared with 1:613 in the south.
- In psychiatric transactions, the native patients were found to be less disturbed by the camera and the off-site voice than were the staff at the hospital.

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Clearinghouse on Development Communication
April 1979

SATELLITE INSTRUCTIONAL TELEVISION EXPERIMENT (SITE)
India

TARGET AUDIENCE:	Inhabitants of 2,400 remote villages in less developed districts of six Indian states, and urban and semi-urban viewers in and around Delhi and Amritsar and in Kheda district of Gujarat
OBJECTIVES:	To develop and assess the potential of a satellite-based instructional television system for national development through formal and nonformal education
MEDIA:	Direct broadcast television via satellite to villages, and rediffusion via urban terrestrial transmitters
DONORS/SPONSORS:	The Indian Space Research Organization (ISRO); the Ministry of Information and Broadcasting; the Ministry of Education; the U.S. National Aeronautics and Space Administration (NASA)
DURATION:	With satellite, one year (August 1975-July 1976); ongoing, relying on terrestrial television transmitters until India's own satellite is ready in 1981
CONTACTS:	Professor E. F. Chitnis, Space Applications Center, ISRO, P.O. Bag 11, Jodphur Tekra, Ahmedabad 380909, India; Professor Bella Mody, Institute for Communication Research, Cypress Hall, Stanford University, Stanford, CA. 94305, U.S.A.

DESCRIPTION:

In August 1975, after six years of planning, India began a unique and massive experiment to support national development through instructional television broadcast via satellite. The primary goal of the Satellite Instructional Television Experiment (SITE) was to provide formal and nonformal educational and cultural programming to villagers in remote rural areas. The U.S. National Aeronautics and Space Administration lent India the ATS-6 satellite for one year, positioning it over the Indian Ocean. The satellite was used to beam programs to community television receivers in 2,400 villages chosen for the experiment (a potential daily audience of 2.8 million). The Indian Space Research Organization (ISRO) was responsible for the hardware ground segment of the experiment; Doordarshan (the Indian national television service) for producing the majority of the programs; and the Space Applications Centre of ISRO for program evaluation.

Programs were broadcast for four hours each day in four of India's 14 major languages, either with separate programs for each language or with a dubbed second sound track. A variety of program formats was used, including lecture-demonstrations, interviews, drama, panel discussions, song and dance, puppets, and response to viewer mail.

The largest amount of programming time was directed toward nonformal education in agriculture, health, and family planning, aimed at a general adult audience. These programs, broadcast for 2 1/2 hours each evening, included a one-half hour national news program in Hindi and 40 minutes to an hour of regional development-oriented programming in Hindi, Telegu, Kannada, and Oriya. The second largest amount of programming time was directed at an in-school audience of children aged 5-12; the broadcasts provided educational enrichment rather than basic curriculum, with a heavy emphasis on science education. School programs were broadcast for 1 1/2 hours each day (22 1/2 minutes in each of the four languages). Teachers were given some training in how to use the television lessons and how to relate them to the child's environment. They were also provided with printed program synopses prior to each broadcast, and with activity suggestions and wall posters. The third major program, teacher training, was conducted during school vacation periods and was part of a larger multimedia course that used other instructional communication methods as well.

Additional ancillary activities and "experiments-within-the-experiment" included a training program for agricultural extension agents and the establishment of an experimental field laboratory for testing grassroots programming approaches. The laboratory broadcast experimental programs to a 40-kilometer radius in Kheda district using a conventional 1kw terrestrial transmitter.

India's major goal was to gain comprehensive experience in developing, testing, and managing a satellite-based instructional television system, in anticipation of its own domestic satellite system. To this end, all of the ground-based material, from electronic hardware to program software, was developed and produced in India. Because the ATS-6 generated higher-powered signals than did earlier satellites, it required a less powerful and less expensive earth station to transmit the signal, which the Indians were able to build with a minimum of imported parts. Similarly, the 2,400 direct reception systems, which consisted of a ten-foot wire-mesh antenna, a front-end converter, and a television monitor, were all manufactured in India, at a cost of about $1,100 each. Special base production centers were established in Cuttack, Hyderabad, and Delhi to produce language- and area-specific programming using one-inch videotape. Four maintenance centers were established in each of the six states, each responsible for keeping 100 community receivers in working order.

SITE was also characterized by a strong research and evaluation component. Audience profiles and needs assessment studies were conducted. A few pilot programs were designed and pretested in villages. During broadcast transmission, there was regular feedback from the audience on message impact and viewing conditions. Anthropologists who went to live in selected villages from six months before SITE until three months after its conclusion performed holistic studies on cultural and communication patterns and how they were influenced by the project. Sociologists conducted surveys on the impact of one year of television on adult villagers. Psychologists studied the impact of television on primary school children.

RESULTS:

Perhaps the most significant outcomes of the SITE project were the successful coordination between the two major government agencies involved, and the successful demonstration of technical and operational expertise on a large scale, using complicated technology in a Third World country. The project gave a geographically and socioeconomically diverse population access to a wide range of information. There were statistically significant gains in knowledge of preventive health measures, family planning, animal breeding, political information, and overall modernity. While television viewing did not displace or increase use of other media, it did increase the villagers' contact with the village-level extension agents. In general, the overall magnitude of knowledge gain was greater for lower castes, illiterates, females, low-income groups, and those who reported regular television viewing, that is, for groups that had less exposure to other information sources.

The first month's high average evening audience size of 300 leveled off to about 50-80 per village after the initial novelty wore off. Daily audience size depended on the agricultural activity levels and the programming expected that evening. The evening audience composition was approximately 50 percent adult males, 20 percent adult females, and 30 percent children. Small farmers and landless laborers formed the majority audience. The feedback study indicated that instructional programs and those with a message were preferred over purely entertainment programs. In the in-school program, children in television classrooms showed significant increases in language development. Television did not, however, have any impact on school enrollment or absenteeism figures. On the technological side, the reliability of village receivers was a little over 90 percent, once initial problems were resolved. Reliability of the main earth stations was about 99 percent.

OF NOTE:

- Thirty-four days before SITE broadcasts were scheduled to start, Indira Gandhi declared an Internal Emergency that involved the full censorship of all media. Many of the news segments were used to transmit information on the Emergency.
- One hundred and fifty battery-operated television sets were installed in one state in an experiment with a different reception possibility. These sets had fewer breakdowns than did those dependent on electricity.
- The SITE research and evaluation plan was conceived as a multidisciplinary exercise, involving over one hundred Indian social scientists and media researchers.
- Eighty-two percent of total SITE costs, roughly $15-$20 million, were incurred on hardware, 9 percent on software, 6 percent on management and coordination, and 3 percent on social research and evaluation.

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Clearinghouse on Development Communication
September 1979

Supported by the U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT • BUREAU FOR SCIENCE AND TECHNOLOGY • OFFICE OF EDUCATION

AED

ACADEMY FOR EDUCATIONAL DEVELOPMENT

PROJECT SUMMARY

RURAL SATELLITE PROGRAM WORLDWIDE

OBJECTIVE: To develop and field-test the use of communication satellite technologies to provide educational information and telecommunication services for rural development in developing countries.

DURATION: 1980 to 1985

SPONSOR: Office of Education, Bureau for Science and Technology; Office of Development Resources, Bureau for Latin America and the Caribbean, U.S. Agency for International Development.

The Academy for Educational Development is administering a five-year program, funded by the U.S. Agency for International Development, to promote the use of satellite technologies for communication services in support of such basic aspects of rural development as health care, agricultural improvement, adult literacy, and classroom education. The program represents a substantial effort by the United States to transfer to developing nations a range of appropriate, cost-effective communication technologies that will enable them to strengthen their total communication systems.

The Rural Satellite Program includes several full-scale pilot projects, each of approximately two years' operation, jointly designed and jointly funded by the U.S. and host country governments. Although individual projects are managed cooperatively during the initial phases, the goal is to transfer the management and operation of the projects entirely to host country personnel. A limited number of satellite earth stations installed in the host countries are helping the participating countries to develop the expertise that will enable them to provide ongoing operational satellite services in rural areas.

The pilot project in Indonesia is putting in place an audio teleconferencing system that will enable the campuses of the Eastern Islands University Association (BKS) to train new faculty, upgrade existing faculty capabilities, increase student access to basic science courses, and increase the availability of specialized faculty and library resources. The pilot project in the Caribbean region is providing an audio teleconferencing system to expand the education and outreach capabilities of the University of the West Indies. The Peru Rural Communication Services Project is establishing a satellite-based communication system to link seven rural communities with each other and with Lima.

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The communication system has a public service focus, providing special services to development ministry personnel working in remote health posts, rural schools, and agricultural extension offices, as well as commercial telephone service. The Academy's management of the pilot projects includes supervision of the engineering subcontract for the design and installation of the hardware system, supervision of the equipment procurement process, and technical assistance for the development of software and appropriate applications of the communication systems.

In addition to the pilot projects that are testing the use of satellite communications in the field, the Rural Satellite Program includes several central activities conducted by the Academy's Washington, D.C., office. One of these central activities is the development of a series of policy studies analyzing the financial, technical, regulatory, and international environments within which developing countries must operate to obtain rural satellite services. The first policy study examines the satellite systems available for providing rural telecommunication services by satellite to developing countries. A second policy study examines the criteria and procedures that agencies use in funding rural telecommunication projects.

Training is another activity of the Rural Satellite Program. Centrally, the program has assessed the capability of academic, government, and business organizations to provide the type of training needed by program participants and representatives from other countries. The capabilities assessed range from development support communications to interactive telecommunication systems for social development services, to economic and technical analysis of satellite systems. The results of these assessments guide the training of project staff from each of the pilot projects in both technical and applications areas.

Information is the third area of central program activity. A resource library of some 1,500 documents for communication satellite applications has been assembled and catalogued to support the program. Uplink, a biannual newsletter, keeps program participants and observers informed about the program itself and about other satellite-related activities. Uplink is supplemented by press releases on current program developments. Special reports and audio-visual products describe the program, and questions are answered through an information service. The cumulative experience of the Rural Satellite Program will be examined at an international conference to be held at the end of the program's five years.

Rural Satellite Program staff also help to coordinate program elements being developed by other agencies. The Institute for Telecommunication Sciences in Boulder, Colorado, has been working with the program to develop a design for an earth station that will provide telecommunication service to rural areas effectively and economically. Also, working with AID's Office of Energy, NASA's Lewis Research Center has conducted research on using solar power to provide low-cost reliable electricity for small earth stations.

AED

ACADEMY FOR EDUCATIONAL DEVELOPMENT

PROJECT SUMMARY

U.S. TELECOMMUNICATIONS TRAINING INSTITUTE WORLDWIDE

The U.S. Telecommunications Training Institute is a unique joint venture of the American telecommunications industry and the U.S. Government to share advances in telecommunications technology with developing countries. It was organized in response to the growing requests to the U.S. for technical assistance to narrow the widening gap between the developed and developing worlds in light of the new technologies which significantly affect worldwide communications systems.

An independent, nonprofit corporation, administered by a Board of Directors representing both industry and government, USTTI has contracted with the International Division of the Academy for Educational Development to administer its operations.

USTTI is an unprecedented response to the call for private sector contributions to international development. During its first training year, through 17 training programs coordinated by USTTI, sponsoring corporations provided tuition-free training to more than 200 telecommunications managers, engineers, and technicians from 65 countries. In offering short-term training programs at the management and advanced technical levels, USTTI seeks to contribute to the strengthening of planning and operations of domestic telecommunications infrastructure as part of national development.

While all courses are provided without charge by the sponsoring corporation or government agency, participants or their nominating organization are responsible for costs of international and domestic U.S. travel, and for living expenses while traveling and during training. USTTI works closely with international donor and assistance agencies to secure scholarship funds to support trainees from the poorest countries who are unable to secure their own financial support. USTTI participants have received funding from a variety of sources including: the ITU Fellows Program, USAID, IPDC/UNESCO, the OAS, Asia Pacific Telecommunity, and the World Bank.

An average of 18 management and technical courses are offered each year in such subjects as switching systems, satellite communications management, high frequency broadcasting, telecommunications planning and economic decision making, and the use of microcomputers in telecommunications. All training programs are offered at the training facility of the sponsoring corporation or government agency, and feature "hands-on" training with the latest equipment or methods.

In addition, the private sector has provided core funding for the administrative operation of the Institute. Corporate sponsors include:

- AT&T International
- COMSAT
- GTE International
- Harris Corporation/ Broadcast Group
- Merrill Lynch & Company
- Northern Telcommunication Corporation
- Wall Street Journal
- Western Union Telegraph Company
- Collins Transmission Systems Division of Rockwell International
- Xerox Corporation
- Motorola, Inc.
- Westinghouse Corporation
- IBM Corporation
- ITT Corporation
- MCI Telecommunications
- RCA Global Communication
- TRT Telecommunications Corporation

The U.S. Telecommunications Training Institute was founded by Ambassador Michael R. Gardner, Chairman of the U.S. Delegation to the Plenipotentiary Conference of the International Telecommunications Union (ITU), held in Nairobi, Kenya, in the Fall of 1982. Members of the Board of Directors include:

Michael R. Gardner, Chairman, Attorney, Akin, Gump, Strauss, Hauer & Feld

Joseph V. Charyk, Chairman of the Board, COMSAT

Robert M. Flanagan, President, Western Union Telegraph Co.

Mark S. Fowler, Chairman, Federal Communications Commission

Robert J. Gressens, President, GTE International

David J. Markey, Assistant Secretary for Communications and Information, National Telecommunications and Information Administration, Department of Commerce

William McGowan, Chairman of the Board, MCI Telecommunications Corporation

Robert Sageman, President, AT&T International

Harrison Schmitt, Former Astronaut and U.S. Senator, New Mexico

William Schneider, Jr., Undersecretary of State for Security Assistance, Science and Technology

Charles Z. Wick, Director, United States Information Agency

Bernard Wunder, Former Assistant Secretary of Commerce for Communications and Information.

Transcending Barriers: SHARING Satellite Technology

by Gail Bouck

In many areas of the world, particularly in developing countries, natural geographic barriers, lack of teachers, diffused populations, and inadequate infrastructures make conventional communication methods either physically or financially impossible. The expanding use of telecommunications, especially new satellite technology, can help overcome such difficulties. Although the use of such technology is likely to be affected by a country's political and economic situation, projects using telecommunications are, nonetheless, being carried out in education, medicine, and agriculture.

Under the auspices of INTELSAT, the 110-member organization which owns the world's international telecommunication satellite system, and in conjunction with the International Institute of Communications, a London-based member organization concerned with the uses and developments of international communication, Project SHARE (Satellites for Health And Rural Education) was initiated in order to make more people aware of the practical uses of satellite communications for educational and health purposes. Since its inception in 1985, it has provided free satellite access for rural health and long-distance educational programs which use new satellite technologies.

Each SHARE project involves a series of tests and/or demonstrations aimed at showing how modern telecommunications can help alleviate the problems inherent in providing rural health care and education. Originally conceived as a 16-month project, scheduled to end in April 1986, it has now been extended through December 1986. To facilitate the development of permanent long-term programs, extensive evaluations and studies will be conducted on each project, as well as on the project as a whole. These will be published and made available upon request to individuals and institutions in the field. (See address at end of article.)

To date, most projects have been affiliated with universities, professional societies, or hospitals, working with the various telecommunication entities in the countries involved. Each sponsor designs and dictates the content of the project and is responsible for securing financial support, whether private or governmental, and for the terrestrial links. Once the project application has been submitted to INTELSAT, it is reviewed by the International Advisory Council – a special panel of experts in international communications from around the world. The review determines if the project fits the image and spirit of Project SHARE, its potential long-term benefits, and the overall feasibility of the proposal.

Exemplary Projects

Thirty-seven different countries are currently participating in Project SHARE. In education, the People's Republic of China uses satellites to transmit daily lectures to university students throughout the country. Called "A TV University," it serves as an example of how standardized education levels can be brought to scattered populations in countries where great distances and geographical barriers make contact difficult. The use of satellites has also been successfully demonstrated for years by both the University of the South Pacific and the University of the West Indies where a high percentage of course completions, along with high test scores, have been achieved. (See *DCR* 24 and 26.)

In order to further professional and vocational education, lectures on water management and engineering sponsored by the Higher Education for Development Organization (HEDCO) are being transmitted on a bimonthly basis from University College, Dublin, Ireland to the University of Amman in Jordan. Approximately three hundred participants, both students and professionals in the field, attend these lectures.

Because providing medical information over great distances is difficult, developed and, to a lesser extent, developing countries are turning to satellite technology. The Miami Children's Hospital is sponsoring a large and very successful project to bring the latest techniques and information on pediatrics to doctors in South and Central America. (See article in this issue.)

In another health project, brain scans are sent via telephone lines from Nairobi, Kenya to St. Johns, Newfoundland, Canada, where diagnoses are performed. This same facility maintains a link with the Makarere Medical Center in Kampala, Uganda to support their small staff of doctors and trained personnel, helping them to serve a much larger population than otherwise would be possible.

More Ideas for SHARE

Other projects also are in various stages of preparation or operation. Some innovative proposals that have been submitted include: using small, transportable microterminals to assist in coordinating famine relief; creating interactive access to international databanks for nutrition education in South Pacific island nations or for children's television programming; and relaying training programs to bring computer literacy to developing nations.

Each SHARE project carries with it a different challenge and has attracted an impressive diversity of individuals and organizations. By taking the initiative, these participants have gained insight into the problems and the promises of telecommunication for their countries. SHARE's ultimate goal, of course, is to stimulate developing countries into future activities on their own, building on the skills acquired while bringing expanded services to rural populations.

For further information about Project SHARE contact: Gail Bouck, INTELSAT, 3400 International Drive, NW, Washington, DC 20008-3089. Telex 89-2707. Telephone (202) 944-7825.

Gail Bouck is Assistant Development Affairs Officer in the Office of Policy Analysis and Development Affairs at INTELSAT where she manages Project SHARE. ■

UPLINK

Number 5
April 1985

the newsletter of the rural satellite program,
a project of the u.s. agency for international development

Low-Earth Orbit Satellites for Development

Dramatic improvements in communciations and information technology over the past decade, coupled with rapidly declining unit costs for such technologies, have given rise to a great deal of speculation on how communications in developing countries stand to benefit from the information revolution. Syntheses of advanced digital techniques and worldwide satellite systems suggest an interconnected world in which North-South and South-South information flows are both more frequent and more efficient.

An enormous communications infrastructure has already been built around Intelsat and domestic satellites in geosynchronous orbit. While these satellites offer a wide real-time spectrum of data, video, and audio capability, high earth station costs and the tendency for these services to be unavailable outside of the major urban areas of developing countries warrant consideration of complementary approaches.

Low-earth orbit (LEO) satellites may be a viable option for those applications where real-time communication is not required and where the cost and/or portability of ground station equipment are strong concerns. Specifically, a LEO satellite in polar orbit has the unique feature of reaching every point on earth two to four times a day. Coupled with a digital "store-and-forward" capability and a reliable data processing format, LEO satellites could fill an important niche in the global communication infrastructure, serving, as Yash Pal has suggested, as a kind of "orbital postman."

Volunteers in Technical Assistance (VITA) and the Radio Amateur Satellite Corporation (AMSAT) have been working jointly for the past two years to develop a satellite to test the development applications of this technology. PACSAT (so named for the "packet radio" communications protocols it employs) is scheduled for launch by the Space Shuttle in January 1987, through NASA's "Get Away Special" program, although technical details of the satellite configuration remain to be worked out depending on the availability of funding. VITA/AMSAT volunteer teams have already designed and built an experimental version of PACSAT that was launched by NASA aboard a British scientific satellite in March 1984.

The design lifetime of PACSAT is 10 years, which means that the satellite is being built to operate for at least ten years. PACSAT will have its own propulsion system to boost it into a permanent orbit once it is launched from the satellite. The ground stations to be used in the system cost between U.S. $2,000 and $3,000, and include a simple VHF/UHF radio transmitter and receiver, a small personal computer, and a terminal node controller. Current plans call for the use of a whip antenna.

Packet radio protocols currently under development will allow for unattended operation of PACSAT. That is, the satellite will automatically establish contact with the ground stations over which it passes, download messages previously stored in its onboard computer for that station, and upload new messages waiting in the ground station's computer. This feature will be particularly useful in query/response applications, for example, requesting technical information or exchanging administrative details on project management. It could be of particular benefit for the coordination of relief efforts after a catastrophe or for providing logistical support to isolated refugee camps.

The possible agricultural applications of PACSAT are of special interest. Accurate and timely information for agricultural decision-making is usually not accessible to farmers and extension workers with limited resources throughout the world. Following are a few examples of agricultural information needs that could be met through access to a LEO network such as PACSAT:

- **Agronomic diagnosis:** Through the use of computer programs widely available to agricultural enterprises, field problems with crops can be analyzed and resolved before significant damage occurs. For example, problems with fertilizer applications, planting schedules, irrigation needs, and varietal selection can be addressed using computer-analyzed data. A farmer compiles relevant site-specific data on climate, soils, crops, and field practices, for transmission via PACSAT to a centralized database. Computer-processed recommendations on the most effective and economical strategy are sent back to the requester.
- **Livestock:** Locally available feedstocks can be combined to produce maximum nutritional quality blends for specific livestock. Via PACSAT, seasonal variations in crop availability, costs, and content can be computer-analyzed at a national or regional agricultural database facility to produce the best possible formulation. Where it has been available, this approach has already resulted in significantly increased productivity and improved livestock health.
- **Database access:** Access to worldwide agricultural databases (e.g., Agricola and Agris) is typically limited to users with elaborate hardware and expensive access rights. Centralized organizations with appropriate licenses could act as linkage to identify relevant databases for a requester, and to conduct specific searches as ordered by PACSAT users.
- **Agriculture computer program service:** Today, agriculture computer programs are so numerous and diverse that no one agent or small agricultural facility could ever retain all the necessary and available programs specific to their needs. Through the PACSAT linkage, the proper program for a particular application could be identified and actually transferred to a requester via the satellite/radio/computer link. In this way, the ground station terminal actually functions as an active computer center.

Assuming a successful launch and following several months of preliminary testing, VITA/AMSAT will embark on a limited period, perhaps of a year, of proof-of-concept testing. Special licenses are being acquired now. The author invites letters of interest from prospective user groups. Please write to the author at Volunteers in Technical Assistance, 1815 N. Lynn Street, Suite 200, Arlington, Virginia 22209, U.S.A.■

—Gary Garriott
Technical Advisor, VITA

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APPENDIX D

Clearinghouse on Development Communication Worldwide
and
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Issues 40 - 54 (1982-1986)

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AED
ACADEMY FOR EDUCATIONAL DEVELOPMENT

PROJECT SUMMARY

CLEARINGHOUSE ON DEVELOPMENT COMMUNICATION WORLDWIDE

OBJECTIVE: To provide information and services to foster the application of appropriate communications technology to Third World development programs.

DURATION: 1972 - ongoing

SPONSOR: Office of Education, Bureau for Science & Technology, Agency for International Development.

The Clearinghouse on Development Communication is an international center for information and materials on communication technology supporting programs throughout the developing world in education, health, family planning, nutrition, agriculture, and community development. The Clearinghouse originally began in 1972 as the Information Center on Instructional Technology. From this beginning, it expanded the scope and nature of its activities to reflect the widening interest of development professionals in applying communication technologies not only in the classroom, but in all sectors of development.

Today the Clearinghouse on Development Communication links a worldwide network of over 5,000 development professionals, and provides regular, up-to-date analysis, reporting, reference, and referral services.

The ongoing information services range from a quarterly topical newsletter to technical information packages compiled in response to individual queries. The publications and services described below are made possible through contract support from the Agency for International Development.

- Development Communication Report: A quarterly newsletter that highlights issues and trends in communication applications for development.
- Project Profiles: Concise information provided to project planners on the use of communication technologies in development projects; available in English, French, Spanish, and Arabic. Currently over 100 projects are included and cross-referenced.
- Information Bulletins: Published on major development communication topics.

- **State-of-the-Art Reviews:** The latest and best thinking in a given area, resulting in:
  - Information packages and design services for seminars in development communication.
  - Media productions illustrating the role of communications in education, agriculture, health, etc.
  - Synthesis of research papers and planning documents relevant to a specific topic.
- **Referral List:** Institutions and individuals in the area of communications and development, categorized by country and professional interest.
- **Technical Information Service:** Tailored information packages provided in response to individual queries.
- **Resource Center:** 15,000 documents on communications, education, and development, as well as films, videotapes, and other illustrative materials on international development and communication. Outstanding features of the resource center are a selection of country-specific materials on communication, unpublished project research, and reports rarely found in other libraries or bibliographies. New materials on communications are added daily to the collection. A partial overview of the collection's organization follows:

Media
- Radio
- Satellites
- Films
- Television
- Audio-visual Aids
- Computers
- Folk Media
- Video
- Audio Cassettes

Content
- Agriculture
- Nutrition
- Training
- Information Management
- Women in Development
- Education/Nonformal Education
- Health
- Population/Family Planning
- Research and Evaluation
- Urban/Rural Development

Geographic Areas
By country or by region:
- Africa
- Latin America
- Asia
- Middle East

Audio-visual Library
- Films
- Audiotapes
- Videotapes
- Slidetapes

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APPENDIX E

International and Regional Institutions in Africa
African-Based Information Centers

FIGURE 3

INTERNATIONAL/REGIONAL INSTITUTIONS

H Headquarters

M = Member Nations

R = Regional Office

S = Subregional Office

*Membership proposed.

	African Regional Centre for Technology (ARCT)	Inter-African Drought Control Centre (AGRHYMET)	International Agricultural Research Centers (IITA)	International Livestock Centre for Africa (ILCA)	Institut Africain pour le Developpement Economique et Social (INADES)	Niger Basin Authority (NBA)	Organisation Africaine de la Propriete Intellectuelle (OAPI)	Organisation pour la Mise en Valeur du Fleuve Senegal (OMVS)	Pan-African Documentation and Information System (PADIS)	Pan-African News Agency (PANA)	Regional Remote Sensing Facility	Sahel Information Network (RESADOC)	Union des Radiodiffusions et Televisions Nationales d'Afrique (URTNA)	United Nations Children's Fund (UNICEF)	United Nations Development Programme (UNDP)	United Nations Economic Commission for Africa (UNECA)	United Nations Educational, Scientific, and Cultural Organization (UNESCO)	United Nations High Commissioner for Refugees (UNHCR)	West Africa Rice Development Association (WARDA)
BENIN	M					M	M		•	•		M	M						M
BOTSWANA				S					•	•			M						
BURUNDI					S				•	•									
CAMEROON	M				S	M	H		•	•		M	M	R		S	S		
CAPE VERDE	M	M							•	•			M						
CENTRAL AFRICAN REPUBLIC							M		•	•		M							
CHAD		M			M	M			•	•		M	M						
COMOROS					S				•	•	M		M						
CONGO							M		•	•		M	M	R					
DJIBOUTI									•	•			M						
ETHIOPIA	M		R	H	S				H	•			M			H	R	R	
EQUATORIAL GUINEA	M								•	•									
GABON							M		•	•		M	M						
GAMBIA		M							•	•			M						M
GHANA	M								•	•			M						M
GUINEA	M					M			•	•			M						M
GUINEA-BISSAU									•	•			M						M
IVORY COAST					H	M	M		•	•		M	M	R					S
KENYA	M		R		S				•	•	H		M	R			R		
LESOTHO									•	•	M								
LIBERIA	M		R						•	•			M						H
MADAGASCAR									•	•									
MALAWI									•	•	M		M						
MALI		M		S		M	M	M	•	•		H	M						S
MAURITANIA	M	M					M	M	•	•		M	M						M
MAURITIUS	M								•	•			M						
NIGER	M	H				H			•	•			M			S			M
NIGERIA	M		R	S		M			•	S							S		S
RWANDA	M				S				•	•						S			
SAO TOME AND PRINCIPE									•	•									
SENEGAL	H	M					M	H	•	H		M	H	R			R	S	S
SEYCHELLES									•	•									
SIERRA LEONE	M								•	•			M						S
SOMALIA	M								•	•	M		M						
SUDAN									•	S			M						
SWAZILAND	M								•	•	M								
TANZANIA	M				S		M		•	•			M						M
TOGO	M				S		M		•	•		M	M						M
UGANDA	M								•	•	M		M						
UPPER VOLTA		M			S	M	S		•	•	H	M	M		S		S		S
ZAIRE	M								•	S			M					S	
ZAMBIA	M				S				•	S	M		M	R		S	S		
ZIMBABWE									•	•									

Source: Academy for Educational Development, Critical Aspects of the Establishment and Utilization of Satellite Services for Africa, p. 71.

FIGURE 4

AFRICAN-BASED INFORMATION CENTERS

N = Information Center/No Data Bank
D = Information Center/Data Bank
* Regional Scope

	Agriculture	Small Scale Agriculture	Rural Development	Health Administration	Mining	Industry	Small Scale Industry	Trade/Commerce	Economics	Meteorology	Natural Resources/Earth Sciences	Energy	Telecommunication	Satellite Technology	TV Production	Radio Production	Educational Planning
BENIN	N				N	N*			N								
BOTSWANA		N	N	N	N	N			N				N			N	
BURUNDI						N		N									N
CAMEROON						D*	D									N	
CAPE VERDE																	
CENTRAL AFRICAN REPUBLIC	N*				N	N		N	N*								
CHAD	N		N			N		N			N		N				
COMOROS																	
CONGO																	
DJIBOUTI																	
ETHIOPIA	N*	N		N	D*	D*	D*	N*	N*		N*	N*	N			N	N
EQUATORIAL GUINEA																	
GABON			N*			N*			N*		N*	N*					
GAMBIA						N			N							N	N
GHANA	D	N	N*	N		N*	N		D*			N*	N*	N		N*	N
GUINEA																	
GUINEA-BISSAU																	
IVORY COAST			N*		N	N	N	N*	N*		N		N		N	N	
KENYA	N		N		D*	D*		D*	N		D*	D*			N	N*	
LESOTHO		N														N	N
LIBERIA	N*								D		N						
MADAGASCAR			N			N		N									N
MALAWI																N	
MALI			N			N*		N									
MAURITANIA						D			D								
MAURITIUS	N					N	N	N	N					N		N	
NIGER	N*					N*				N*	N*	N*			N	N	
NIGERIA	N*					D*		D*	D*		N*			N	N		N
RWANDA						D*					N*	N*					N
SAO TOME AND PRINCIPE																	
SENEGAL	D*		D*	D*	N	D*	N		N		D*	D*				N	N*
SEYCHELLES																	
SIERRA LEONE			N*						N*							N	
SOMALIA	N*					N			N*							N	
SUDAN						D*		D					N	N	N	N	
SWAZILAND									N							N	
TANZANIA	N*		N*	N*		D*	N	N*	N*			N				N	
TOGO						N	N										
UGANDA						N*		N*	N*				N				
UPPER VOLTA	N*					D		D	D	N*	N*	N*	N			N	N*
ZAIRE						N*			D			N	N	N			D
ZAMBIA	N*		D*		N*	N*	N*	N*	N*		N*	N*	N	N	N	N	N
ZIMBABWE																	

The major sources for this chart were: UNIDO, Directory of International Information Services and Systems in Developing Countries (Vienna, Austria: United Nations Industrial Development Organization 1981), and USAID, Directory of Development Resources (Washington, D.C.: U.S. Agency for International Development, 1981).

Source: Academy for Educational Development, Critical Aspects of the Establishment and Utilization of Satellite Services for Africa, p. 74.